The Great Grid Upgrade

Eastern Green Link

Eastern Green Link 3 and 4

Strategic Options Report

February 2024

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Executive Summary

Purpose of this Report

Consistent with the Government's Net Zero target of connecting up to 50 gigawatts (GW) of offshore wind by 2030, there has been, and continues to be, growth in the volume of renewable and zero carbon generation that is seeking to connect to the electricity transmission system in Scotland, England and significantly in areas of the East Coast of England.

The need for a co-ordinated strategy to meet the 2030 Net Zero target is reflected in the emerging draft National Policy Statement for Electricity Networks Infrastructure (EN-5), which identifies a policy imperative in support of offshore-onshore transmission. This is further reflected in the Holistic Network Design (HND) prepared by National Grid Electricity System Operator (ESO) that then identifies the pathway programme for the transmission infrastructure needed, both onshore and offshore, to support new generation developments.

A need for new cross border reinforcements of the electricity transmission system between the north east and east coast of Scotland and the east coast of England, has been identified by the ESO. These requirements form the basis of recommendations that the ESO makes to transmission system owners including National Grid Electricity Transmission plc (NGET). NGET is continuing to develop a set of reinforcement proposals that would contribute to meeting the requirements for cross border transmission system reinforcements identified by the ESO.

As part of the ESO recommendation, a need was identified for two new 2GW HVDC links between Scotland and the South Humber area. This report provides an overview of the Eastern Green Link 3 (EGL3) and 4 (EGL4) projects that NGET is developing for the connection to the transmission system in the eastern England area, of new HVDC links

- Eastern Green Link 3 (NOA reference E4L5): 2GW HVDC link between Peterhead, Aberdeenshire in Scotland and Northwest Norfolk region in England. It will be developed as a Joint Venture by National Grid Electricity Transmission (NGET) and Scottish and Southern Electricity Network (SSEN).
- Eastern Green Link 4 (NOA Reference TGDC): 2GW HVDC link between Westfield, Fife in Scotland and Northwest Norfolk region in England. It will be developed as a Joint Venture by National Grid Electricity Transmission (NGET) and Scottish Power Transmission (SPT).

The stages of NGET's process based approach when a need is identified for transmission system works that would require additional consents and/or permissions, are shown below:

Figure A – Approach to consenting process

This report forms part of the initial 'Options identification and selection' stage.

This executive summary provides an overview of the contents of this report and highlights key areas relevant to this consultation including:

- reasons why the transmission system in Scotland, England and significantly in areas of the East Coast of England, need to change;
- a summary description of the options for providing additional transmission system capability that were identified by NGET as potential strategic options;
- how NGET evaluated the identified potential strategic options;
- the rationale for NGET's preferred strategic option selection decision, and
- confirms the option that NGET intends to take forward to the 'Defined proposal and statutory consultation' stage.

National Grid Electricity Transmission

NGET is the owner of the transmission system in England and Wales and holds an electricity transmission licence that permits transmission ownership activities. Our transmission licence requires that we provide an efficient, economic and co-ordinated transmission system in England and Wales.

NGET, as the regulated provider of electricity transmission services in England and Wales, is regulated by the Office of Gas and Electricity Markets ('Ofgem'). Transmission services include maintaining reliable electricity supplies and offering to construct new transmission system assets for new connections to the National Electricity Transmission System ('NETS').

In accordance with transmission licence requirements, we ensure that the transmission system in England and Wales meets the requirements in respect of transmission system security and quality of service at all times. As part of this requirement, we must ensure that sufficient transmission system capability is provided to meet demand and generator customer requirements and wider transmission system needs that exist and/or are expected. When planning changes to our transmission system, we must be efficient, co-ordinated and economical and have regard to the desirability of preserving amenity, in line with the duties under sections 9 and 38 of the Electricity Act.

The electricity transmission system

The transmission system in England and Wales serves the purpose of transporting large amounts of energy across the country. The system connects large energy generators such as wind farms, nuclear or combined cycle gas turbine (CCGT) facilities, to name but a few, with distribution systems which take energy on to the homes and businesses across England and Wales. Transmission voltages up to 400,000 volts (400 kV) are used to move bulk energy, because at this voltage level, it is possible to transport the energy whilst also minimising the amount of power lost through electrical properties of the circuits. The transmission system connects to distribution systems across the country, which in turn transport energy on to homes and businesses across England and Wales, reducing the voltage as the energy progresses through the system. Significant amounts of energy are especially drawn from the transmission system at large demand centres like the M62/M18 corridor, the Midlands, the M4 corridor and the South East.

As we decarbonise our economy, demand for electricity is expected to rise across the whole country, as we use electrified transport and heat our homes, and reduce our reliance on fossil fuels. Originally the transmission system was constructed in the 1960's to move power mainly from the coal fired power stations based near the coal fields of the North and Midlands to 'demand centres'. As we look to the future of energy generation, more low carbon generation such as nuclear and wind is connecting to the system. This low carbon generation is located away from the older fossil fuel power stations. This, alongside growing demand needed to decarbonise our economy, is requiring the transmission system to change and in some cases increased capacity transmission infrastructure is required.

The need case

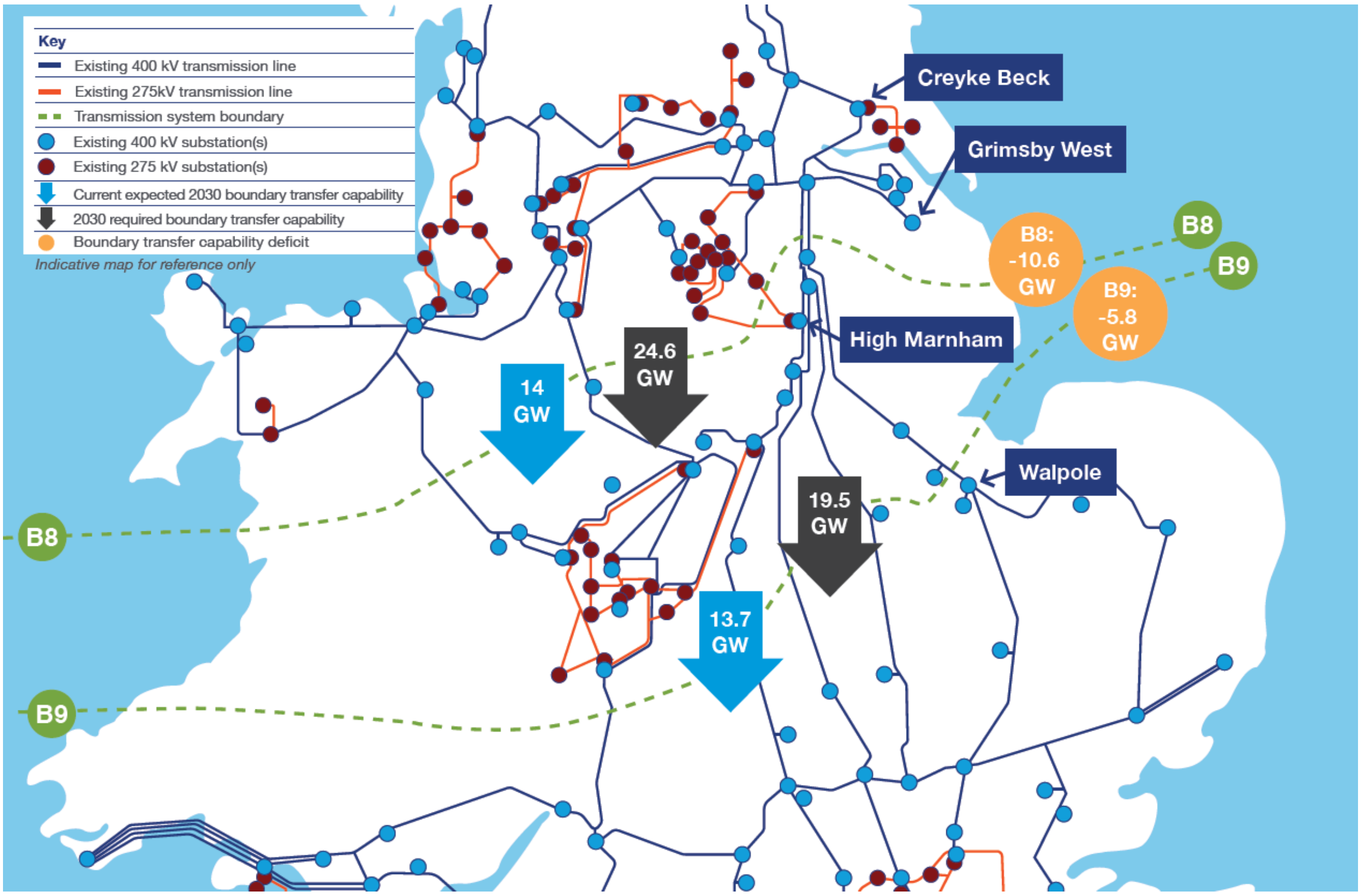
NGET's transmission system needs to comply with the requirements within the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS). When assessing NETS SQSS compliance, NGET considers power flows on critical circuit paths (System Boundaries) on the transmission system. Computer based analysis based on system boundaries is used to assess the impact of new changes to connected customer requirements on power transfers between separate areas of the transmission system. This requirement has been identified within the Economy Planned Transfer assessment as set out in the NETS SQSS.

The analysis carried out took account of changes to the contracted background and the user connections expected in 2030. This assessment considers the amount of generation forecast to cross a boundary by 2030. The system boundaries considered as part of our assessment and referred to in this report are:

- B6 - SP Transmission to NGET
- B7a - Upper North of England
- B8 - North of England to Midlands, and
- B9 - Midlands to South of England.

Each of the circuits which cross the system boundaries identified above has a capacity during the winter Average Cold Spell (ACS) period. This is referred to as the pre-fault capacity. The post fault capacity is defined by the remaining capacity across a boundary following the worst fault which in this context, is referred to as a secured event.

Figure B – Additional system boundary capability required by 2030



In line with the recommendation from the ESO and for the purposes of the initial power system analysis, it was assumed that each of EGL3 and EGL4 would be connected to NGET's transmission system in the South Humber area. The boundary requirements were based on the ESO's Future Energy Scenarios (FES) and the Electricity Ten Year Statement (ETYS), and are an average of the capability needed to meet 90% of network conditions across the three FES that meet the government's net zero ambition.

Table A summarises the results from our assessment of the existing transmission system capacity/capability and the volume of additional transmission system capacity/capability needed to meet the boundary requirements of 2030. Where Capacity is the physical capability of the circuit and Capability is natural flow of power through the circuit, which will be less than the physical capability.

Table A – Additional transmission system boundary capability required by 2030 by last contracted date

System Boundary	Export	Pre 2030 Post Fault Capability	Pre 2030 Post Fault Capacity	Capability Deficit	Capacity Deficit
	MW	MW	MW	**MW**	**(MW)**
B6 – 2030 (system boundary)	21,760	11,500	11,611	**-10,260**	**-10,149**
B7a – 2030 (system boundary)	23,754	13,400	15,623	**-10,354**	**-8,131**
B8 – 2030 (system boundary)	24,632	14,000	17,426	**-10,632**	**-7,206**
B9 – 2030 (system boundary)	19,570	13,700	18,033	**-5,870**	**-1,537**

Based on the outputs from our assessment of the impact of the connection of two new 2GW HVDC links in the South Humber area, requirements for additional transmission capacity/capability across each of the B6, B7a, B8 and B9 system boundaries were identified. Additional transmission system capability is needed so that all transmission licence obligations can be met.

In areas with multiple transmission system change requirements which impact on the same system boundaries, NGET also considers possible impacts of interaction between proposals that are being developed, but consents have not yet been applied for. Due to the volume of changes being sought within the Eastern England region currently, the analysis was not able to take account of all transmission changes that may be identified, proposed and/or delivered before 2030. Any changes which impact the proposal, should they occur, would be addressed through our backcheck and review process, which will be undertaken at key project stages up to and including Development Consent Order Submission.

Identification of Potential Strategic Options for EGL3 and EGL4

NGET considered locations where each (or both) of the new 2GW HVDC links could be connected to the existing transmission system within Eastern England. At the initial stage of this options identification process, we considered locations at (or close to) existing (or already planned) NGET substations. We then applied a technical filter to verify that each identified option would meet the need without requiring substantive additional (compared to other identified options) transmission system reinforcement works.

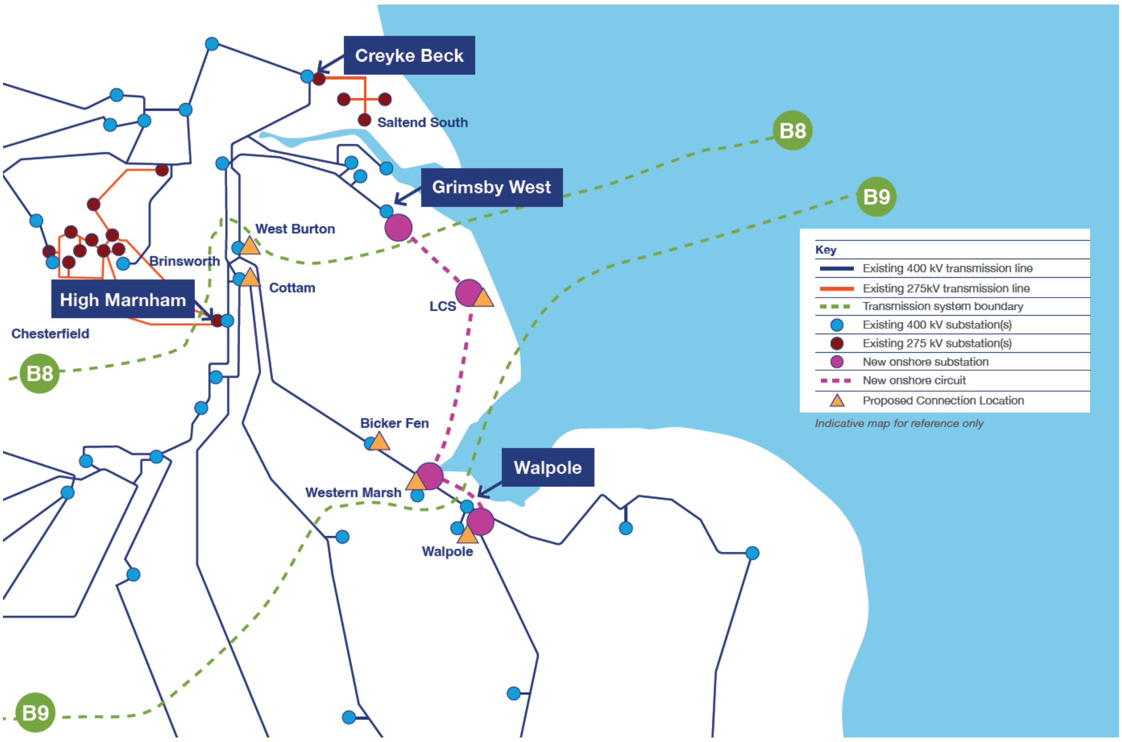
We identified the following options for the connection of both of the new 2GW HVDC links at (or close to) NGET substations (existing or already planned) at:

- West Burton
- Cottam

- Bicker Fen
- Weston Marsh[1]
- Lincolnshire Connection substation(s)[2]
- Walpole.

Based on these six possible locations, NGET identified seven potential strategic options which were taken forward to appraisal. Figure C below shows a geographical indication of the six substation connection locations appraised as part of this report.

Figure C – Geographical indication of strategic options appraised



Appraisal of Potential Strategic Options

When developing and assessing each of the potential strategic options, we have considered the:

- Need for reinforcement as a consequence of ESO recommendations for the connection of two new HVDC circuits in the South Humber area (provided in the HND and NOA publications), and

[1] Development of the new Weston March substation forms part of the preferred strategic option for NGET's Grimsby – Walpole project (ECO5).

[2] Development of the new Lincolnshire Connections substation(s) forms part of the preferred strategic option for NGET's Grimsby – Walpole project (ECO5).

- possible interaction of EGL3 and EGL4's connection locations with other reinforcement proposals that would impact on the capability of system boundary B8 (that NGET is currently progressing as part of the North Humber to High Marnham and Grimsby to Walpole projects).

At this development stage, potential strategic options are evaluated in respect of environmental constraints, socio-economic effects, technology alternatives, capital and lifetime costs. For this strategic options appraisal, each option was considered using information appropriate to the initial development stage and on the assumption that the option is deliverable within a timescale that meets the identified need case.

Table B summarises the potential strategic options that were considered:

Table B – Potential Strategic Options Considered

Reference Number	Potential Strategic Option	Estimated Circuit Length for		Estimated Total Circuit Length for Both HVDC Links
		EGL3 Connection	EGL4 Connection	
EGL OPP1	West Burton substation	625km	521km	**1146 km**
EGL OPP2	Cottam substation	655km	551km	**1206 km**
EGL OPP3	Bicker Fen substation	620km	516km	**1136 km**
EGL OPP4	New Weston Marsh substation	627km	523km	**1150km**
EGL OPP5	New Lincolnshire Connection substation(s)	565km	461km	**1026km**
EGL OPP6	New Walpole substation	640km	536km	**1176km**
EGL OPP7	New Walpole substation with three ended link	645km	541km	**1186km**

All the options set out in Table B were appraised for the purposes of identifying an initial preferred option:

- for NGET's transmission system development proposals and
- to provide relevant information as inputs needed for the ESO's cost benefit analysis (CBA) process.

Constraint cost evaluation is carried out by the ESO and is captured in their independent CBA process and is regularly evaluated and reported in NOA publications.

The appraisal of potential strategic options considered the likely environmental and socio economic effects, technical issues and cost that would be associated with each of the seven potential strategic options.

At the initial appraisal stage, National Grid prepares indicative estimates of the capital costs. These indicative estimates are based on the high-level scope of works defined for each Strategic Option in respect of each technology option that is considered to be feasible. As these estimates are prepared before detailed design work has been carried out, National Grid takes account of equivalent assumptions for each option. Final project costs for any solution taken forward following detailed design and risk mitigation will be in excess of any high-level appraisal cost. However, all options would incur these increases in the development of a detailed solution.

Five of the seven identified potential strategic options (EGL OPP1 to 5) are below the B8 but above the B9 system boundary. However, in line with the recommendation from the North Humber to High Marnham and Grimsby to Walpole Strategic Options Report, one of the identified connection locations (the new Walpole substation) is below the B9 system boundary for which two potential strategic options (EGL OPP6 and EGL OPP7) were identified.

Preferred Strategic Option Selection

For each of potential strategic option EGL OPP1, EGL OPP2 and EGL OPP6 (via a landfall on the Norfolk coastline) additional statutory designations were identified which could be impacted on. In environmental terms, the other potential strategic options are broadly comparable (except with regard to length of cable route required) the potential impact on statutory designations is mainly limited to the marine route/landfall and therefore common to all options. Therefore, NGET considered that each of potential strategic options EGL OPP1, EGL OPP2 and EGL OPP6 (via a landfall on the Norfolk coastline), were less preferable than other strategic options for environmental reasons.

One of the key differentiators between options relates to overall route length which can impact the extent of environmental and socio-economic effects. Reflecting the location of the relevant NGET substation (existing or planned), the total route length for each of the EGL3 and EGL4 potential strategic options ranged between 1,026km (EGL OPP5) and 1,206km (EGL OPP2). With the exception of EGL OPP5, each of the strategic options would require a long length of cable between landfall and substation connection point.

Results from our technical appraisal were used to identify the potential strategic options that would not fully meet the need case associated with the connection two new 2GW HVDC links to NGET's transmission system. We established that additional reinforcement works would need to be carried out in addition to any of potential strategic options EGL OPP 1 to 5, to fully resolve the need case (set out in Section 4).

Capital and lifetime costs were assessed for each of the potential strategic options. Based on this high level assessment of costs, we noted that whilst the capital cost estimate for EGL OPP6 (new Walpole substation via a landfall on the Lincolnshire coastline) is circa £100m higher than option EGL OPP5 (new Lincolnshire Connection substation(s)), the lifetime cost estimate for EGL OPP6 is circa £150m lower than option EGL OPP5. The lowest cost option to fully resolve the need case, was identified as EGL OPP6 a connection of the two new HVDC links to the new Walpole substation (via a landfall on the Lincolnshire coastline) with estimates of a capital cost £4,822.6m and lifetime cost of £5,134m.

Conclusions

We consider that to address the need case (set out in Section 4) and considering the outputs from our appraisal of environmental, socio-economic, technical and cost differentiators, that potential strategic option EGL OPP6 (new Walpole substation via a landfall on Lincolnshire coastline) should be progressed to the next development stage.

NGET proposes to develop EGL3 and EGL4 as two new 2GW HVDC cable connections (each of which is primarily subsea, with a land-based route in England from a landfall on the Lincolnshire coastline), with one converter station per circuit which is located in the vicinity of and connected to the new Walpole substation.

There is not a current requirement to provide a three ended connection to Lincolnshire Connection substation(s) (as described in EGL OPP7), to meet the need case for EGL3 and EGL4. However, NGET considers that the option developed to meet the EGL 3 and EGL4 need case, should have the ability to be changed in the future, to provide a three ended connection to the Lincolnshire Connection substation(s) should additional capacity be required.

This has been assigned the project title of 'Eastern Green Link 3 and 4'. The EGL3 and EGL4 connection projects will now be taken forward to the next stage of development. This involves identification of a preliminary cable corridor and graduated swathe, which indicates a more likely location for the development. This will be consulted on at non statutory consultation, to seek feedback from consultees and help shape the further development of the projects.

Glossary of Terms and Acronyms

AC		Alternating Current
ACS		Average Cold Spell
AC Cable		AC Underground Cable
AONB		Area of Outstanding Natural Beauty
ASTI		Accelerated Strategic Transmission Investment
CBA		Cost benefit analysis
CCC		Committee on Climate Change
Conductor		used to transport power
Constraint costs		payments made to constrain generation, to manage power flows where forecast power flows would exceed to capability of the electricity transmission system
CSC		Current Source Converter
DC		Direct Current
DCO		Development Consent Order issued under the Planning Act 2008
Double circuit		two transmission circuits each consisting of three conductors (one for each phase of the three phase circuits) carried on two sides of a single pylon
Economy Planned Transfer Assessment		Modelling approach for the Economy Planned Transfer Assessment is set out in NETS SQSS Appendix E
Electricity Act		The Electricity Act 1989
EN-1		Overarching National Policy Statement for Energy
EN-3		National Policy Statement for Renewable Energy Infrastructure
EN-5		National Policy Statement for Electricity Network Infrastructure
EN-6		National Policy Statement for Nuclear Power Generation
ESO		Electricity System Operator The operator of the National Electricity Transmission System.
ETYS		Electricity Ten Year Statement The ETYS sets out the ESO's view of future transmission requirements and areas where the

		capability of the transmission network might need to be addressed over the next decade.
FES		Future Energy Scenarios Prepared by the ESO, the FES represents different credible scenarios for the transition to a cleaner greener energy future by 2050.
GIL		Gas Insulated Lines
HND		Holistic Network Design The HND issuedby the ESO in July 2022, sets out a single integrated transmission network design that supports the large-scale delivery of electricity generated from offshore wind by 2030.
HVDC		High Voltage Direct Current
IET, PB/CCI Report		an independent report endorsed by the Institution of Engineering and Technology by Parsons Brinckerhoff in association with Cable Consulting International
Insulators		used to safely connect conductors to pylons
IPC		Infrastructure Planning Commission
MCZ		Marine Conservation Zone
MITS		Main interconnected transmission system
National Grid		the group of companies that includes NGET and the ESO
Need Case		sets out the reasons why transmission system reinforcement is required
Net zero		UK Government's commitment to reduce greenhouse gas emissions to net zero by 2050 as per the Climate Change Act 2008 (2050 Target Amendment) Order 2019
NETS		National Electricity Transmission System
NETS SQSS		National Electricity Transmission System Security and Quality of Supply Standard
NIC		National Infrastructure Commission
NOA		Network Options Assessment Where a requirement for additional transmission network capacity has been identified, the NOA process (undertaken by ESO), is used to identify and assess a range of reinforcement options. ESO recommendations for reinforcement options assessed as economic are published as part of the NOA report.
NPS		National Policy Statements

NPV		Net Present Value
NSIP		Nationally Significant Infrastructure Project
Ofgem		The Office of Gas and Electricity Markets
OHL		Overhead Line
Planned Transfer		the amount of power which will flow out of a region at ACS peak The Planned Transfers for a region of the NETS is calculated using the modelling approach set out in the NET SQSS.
(the) Policy		National Grid's Stakeholder, Community and Amenity Policy
Pylons		used to support conductors
RIBA		Royal Institute of British Architects
SACs		Special Areas for Conservation
SF_6		Sulphur Hexafluoride (gas used to provide electrical insulation)
SGT		Super-Grid Transformer
SPAs		Special Protection Areas
Span length		distance between adjacent pylons
SSSIs		Sites of Special Scientific Interest
STC		System Operator – Transmission Owner Code
Strategic options appraisal		a robust and transparent process used to compare options and to assess the positive and negative effects they may have across a wide range of criteria including environmental, socio-economic, technical and cost factors.
Study area		a defined geographic area used for the purpose of strategic option appraisal
Substation		a secure compound containing electrical equipment through which electrical energy is passed for transmission, transformation, distribution or switching purposes
TEC		Transmission Entry Capacity
Technical filter		analysis to verify that an option would meet the identified need case and is suitable to be progressed as a potential strategic option for appraisal
The Authority		Gas and Electricity Markets Authority, the governing body of Ofgem
T-pylon		monopole pylon design developed by National Grid

Transmission Licence		Licence granted under Section 6(1)(b) of the Electricity Act
volt (V)		rhe SI unit of potential difference 1 kilovolt (kV) = 1,000volts
watt (W)		the SI unit of power 1 kilowatt (kW) = 1,000watts 1 megawatt (MW) = 1,000kW 1 gigawatt (GW) = 1,000MW

1. Introduction

1.1 About this Report

1.1.1 This Strategic Options Review (this report) has been prepared by National Grid Electricity Transmission plc (NGET) as part of the decision making process involved in promoting new transmission projects. It records how NGET has had regard to a range of considerations in developing those projects. This report has been prepared in accordance with NGET's document '*Our Approach to Consenting*'[3].

1.1.2 Consistent with the Government's Net Zero target of connecting up to 50 gigawatts (GW) of offshore wind by 2030, there has been, and continues to be, growth in the volume of renewable and zero carbon generation that is seeking to connect to the electricity transmission system in Scotland, England and significantly in areas of the East Coast of England.

1.1.3 A need for new cross border reinforcements of the electricity transmission system between the north east and east coast of Scotland and the east coast of England, has been identified by the National Grid Electricity System Operator (ESO). These requirements form the basis of recommendations that the ESO makes to transmission system owners including NGET. We are continuing to develop a set of reinforcement proposals that would contribute to meeting the requirements for cross border transmission system reinforcements identified by the ESO.

1.1.4 As part of the ESO recommendation, a need was identified for two new 2GW HVDC links between Scotland and the South Humber area. This report provides an overview of the Eastern Green Link 3 (EGL3) and 4 (EGL4) projects that NGET is developing for the connection to the transmission system in the eastern England area, of new HVDC links:

- Eastern Green Link 3 (NOA reference E4L5): 2GW HVDC link between Peterhead, Aberdeenshire in Scotland and Northwest Norfolk region in England. It will be developed as a Joint Venture by National Grid Electricity Transmission (NGET) and Scottish and Southern Electricity Network (SSEN).
- Eastern Green Link 4 (NOA Reference TGDC): 2GW HVDC link between Westfield, Fife in Scotland and Northwest Norfolk region in England. It will be developed as a Joint Venture by National Grid Electricity Transmission (NGET) and Scottish Power Transmission (SPT).

1.1.5 This report addresses two projects in particular, the EGL3 and EGL4 projects (the Projects). The Projects are described in greater detail later in this report. This consideration of strategic options is part of an iterative process as part of which NGET considers how each of the strategic options for the Projects could interact with other proposals for transmission system reinforcement that are also being progressed.

1.1.6 As set out in '*Our Approach to Consenting*' there are 5 stages. The "Options identification and selection stage" is at the very start of the process (as shown below).

[3] Our Approach to Consenting, National Grid (April 2022) https://www.nationalgrid.com/electricity-transmission/document/142336/download

Figure 1.1 – Approach to consenting process

1.1.7 This report is a key output from the initial stage of this our approach to consenting process and provides scheme development information to support non-statutory consultation.

1.1.8 As we continue to develop our plans and as our proposals evolve, we keep strategic options under review, taking account of consultation feedback and any changes that might influence the assessment of technical, environmental, socio-economic and cost considerations.

1.2 Report Structure

1.2.1 The report is structured as follows:

- Background to England and Wales electricity transmission system (Section 2).
- Reasons why NGET's transmission system needs to develop (Section 3)
- EGL3 and EGL4 need case (Section 4)
- Identification of potential strategic options (Section 5)
- Appraisal of potential strategic options (Section 6)
- Appraisal of strategic options (Section 7,8,9,10,11,12,13)
- Conclusion and next steps (Section 14)

1.2.2 This document is also supported by a detailed set of documents setting out NGET's obligations, technology assumptions and cost appraisal methodology. The supporting document is called "Strategic options technical appendix 2020/2021 price base" and is attached as an appendix to this report. The Appendix to this report also includes a technical evaluation of a land based option as point of comparison for our proposals.

2. Background to the Transmission System in England and Wales

2.1 Background

2.1.1 In 2019 the Committee on Climate Change (CCC) published its Net Zero report setting out recommendations to the UK Government on long term emissions targets for the UK. The Government subsequently adopted the Climate Change Act 2008 (2050 Target Amendment) Order 2019[4], which increased its pledge to achieve 100% reduction in emissions by 2050. One of the ways this will be achieved is through decarbonisation, including moving away from fossil fuels providing energy to our homes and businesses. The vision for a transition to clean energy was set out in December 2020 with the publication of the Energy White Paper[5], which added further detail to the Prime Minister's Ten Point Plan for a Green Industrial Revolution. This requires the adoption of alternative sources of energy to power our homes, transport and businesses.

2.1.2 As a result, electricity production is now moving towards reducing greenhouse gas emissions, by increasing renewable and low carbon sources, such as offshore and onshore wind, solar energy and new nuclear generation. The National Infrastructure Commission (NIC) has published a report recommending to the UK Government that renewable generation[6] can be increased to 65% of supply by 2030 at no adverse cost to consumers, enabling the decarbonisation in part of sectors such as transport and heating via electrification.

2.1.3 Following the publication of the NIC report, the UK Government published the British Energy Security Strategy[7] in April 2022 setting out a strategy for secure, clean and affordable British energy for the long term. This strategy sets out energy ambition across a number of sectors such as, including:

- Up to 8 reactors of nuclear energy being progressed reaching up to 24GW to be achieved by 2050;
- Up to 50GW of offshore wind connected by 2030 including 5GW of which will be offshore floating wind;
- Up to 10GW of low carbon hydrogen production capacity by 2030, doubling the previous ambition; and
- 600,000 heat pump installations a year by 2028 and improving housing stock insulation.

[4] Net Zero the UK's Contribution to stopping global warming, Committee on Climate Change (2019) https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-The-UKs-contribution-to-stopping-global-warming.pdf

[5] Energy White Paper: Powering our net zero future, HM Government (December 2020) . https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future

[6] Operability of highly renewable electricity systems, National Infrastructure Commission (2021) https://nic.org.uk/studies-reports/operability-highly-renewable-electricity-systems/

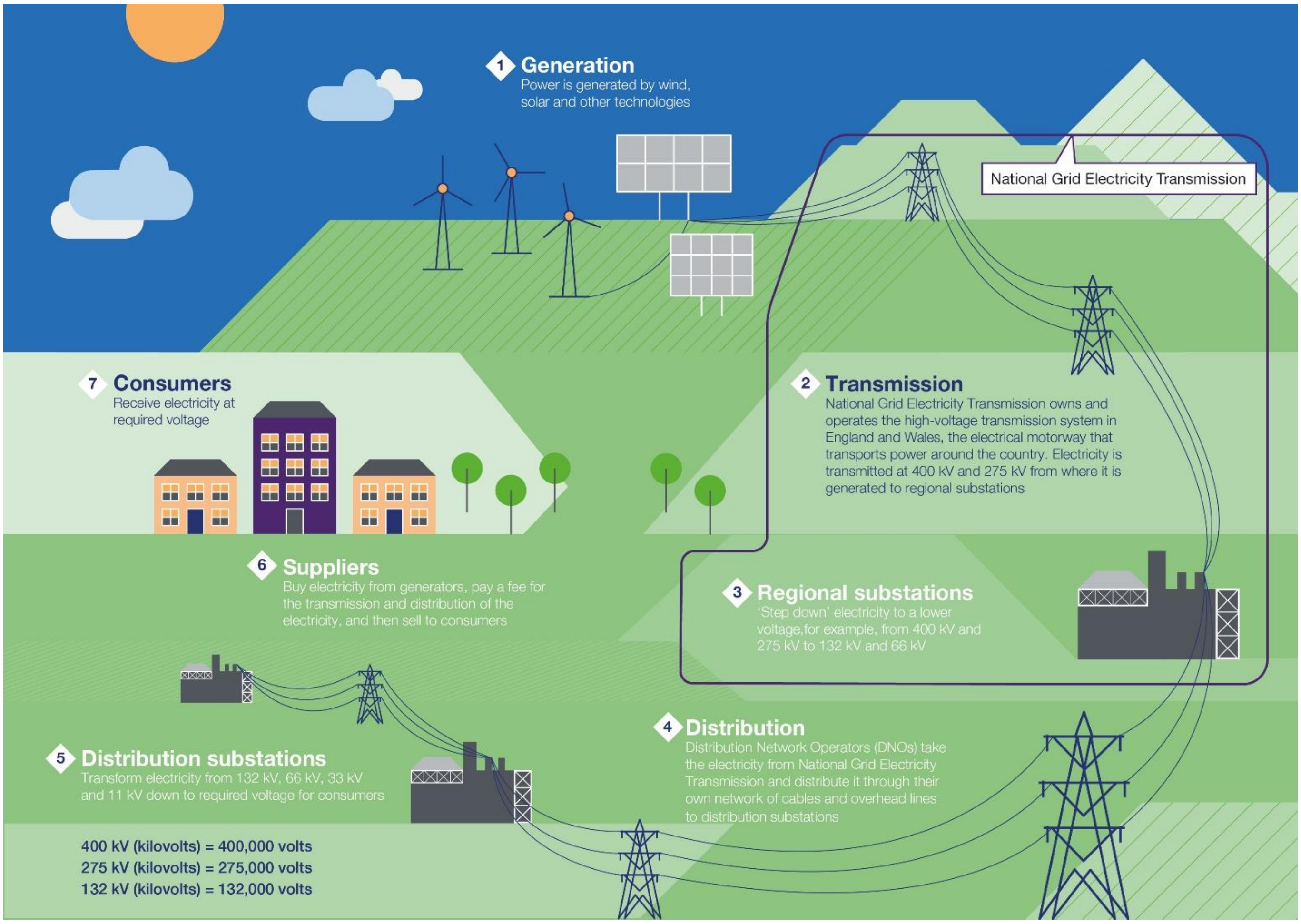
[7] Department for Business, Energy & Industrial Strategy. Policy paper: British energy security strategy, HM Government (2022). Available at: https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy

2.1.4 The Powering Up Britain paper was published in March 2023 by the UK Government. This document provides an update of the strategy for secure, clean and affordable British energy for the long-term future, and closely relates to the points raised in Section 2.1.3.

2.1.5 To facilitate these ambitions, electricity network infrastructure is needed to ensure that energy can be transported from where it is generated to where it is used.

2.1.6 The existing transmission system operates at 400 kV and 275 kV and transports bulk supplies of electricity from generating stations to demand centres. Distribution systems operate at 132 kV and below in England and Wales and are mainly used to transport electricity from bulk infeed points (interface points with the transmission system) to the majority of end customers. See Figure 2.1 below.

Figure 2.1 – The electricity system from generator to customer



2.1.7 A single electricity market serves the whole of Great Britain. In this competitive wholesale market, generators and suppliers trade electricity on a half hourly basis. Generators produce electricity from a variety of energy sources, including coal, gas, nuclear and wind, and sell energy produced in the wholesale market. Suppliers purchase electricity in the wholesale market and supply to end customers.

2.1.8 Electricity can also be traded on the single market in Great Britain by generators and suppliers in other European countries. Interconnectors with transmission systems in France, Northern Ireland, Belgium, Denmark and the Netherlands are used to import electricity to and/or export electricity from the transmission system.

2.2 NGET's role

2.2.1 NGET is the owner of the high voltage transmission system in England and Wales and is part of the National Grid Group of companies.

2.2.2 Transmission of electricity in Great Britain requires permission by a licence granted under Section 6(1)(b) of the Electricity Act 1989[8] (as amended) (the Electricity Act). NGET has been granted a transmission licence (the Transmission Licence) and is therefore bound by legal obligations, which are primarily set out in the Electricity Act and the Transmission Licence. In its role in providing transmission services in England and Wales, NGET is regulated by the Office of Gas and Electricity Markets ('Ofgem').

2.2.3 NGET's legal obligations include duties under section 9, section 38 and Schedule 9 of the Electricity Act. In summary, these require NGET to:

- develop and maintain an efficient, co-ordinated and economical system of electricity transmission;
- when formulating proposals for the installation of electric line or the execution of any other works for or in connection with the transmission or supply of electricity, have regard to the desirability of preserving natural beauty, of conserving flora, fauna and geological or physiographical features of special interest and of protecting sites, buildings and objects of architectural, historic or archaeological interest; and
- when formulating such proposals, do what it reasonably can to mitigate any effect which the proposals would have on the natural beauty of the countryside or on any such flora, fauna, features, sites, buildings or objects.

2.2.4 A fuller consideration of NGET's legal duties is set out in Appendix A.

2.2.5 The ESO is a separate legal entity to NGET, but as of 2023 is still part of the National Grid Group. The ESO facilitates several roles on behalf of the electricity industry, including making formal offers to connection applicants to the National Electricity Transmission System (NETS).

2.2.6 NGET is obligated to provide the physical connections to the elements of the NETS that NGET own.

2.3 NGET's existing transmission system

2.3.1 The electricity transmission system is a means of transmitting electricity around the country from where it is generated to where it is needed. The existing transmission system was developed to transport electricity in bulk from power stations to demand centres. Much of NGET's transmission system was originally constructed in the 1960s. Incremental changes to the transmission system have subsequently been made to meet increasing customer demand and to connect new power stations and interconnectors with other transmission systems.

2.3.2 NGET's transmission system consists of approximately 7,200 km of overhead lines and a further 700 km of underground cabling, operating at 400 kV and 275 kV. In general, 400 kV circuits have a higher power carrying capability than 275 kV circuits. These overhead line and underground cable circuits connect around 340 substations forming a

[8] Electricity Act 1989, c. 29., HM Government (1989 as amended) https://www.legislation.gov.uk/ukpga/1989/29/contents

highly interconnected transmission system. Further details of the transmission system including geographic and schematic representations are published by the ESO annually as part of its Electricity Ten Year Statement[9] (ETYS).

2.3.3 NGET provides a connection between large generation stations and the connection of demand for homes and businesses in England and Wales. The generation directly connected to the electricity transmission system tends to be of two types: low carbon energy (nuclear, wind farms, solar) and large thermal generation (gas powered generation and older fossil fuel powered generation). This is also supplemented by new storage technologies such as battery storage and hydro storage.

2.3.4 Circuits are those parts of the system used to connect between substations on the transmission system. The system is mostly composed of double circuits (in the case of overhead lines carried on two sides of a single pylon) and single circuits. Substations provide points of connection to the transmission system for power stations, distribution networks, transmission connected demand customers (e.g. large industrial customers) and interconnectors.

2.4 How the transmission system operates

2.4.1 A generation group consists of a number of existing generating stations and / or proposed generating stations connecting in a particular geographical area of the transmission system.

2.4.2 Proposed generating stations require a connection agreement with the ESO to authorise their connection to the transmission system. The relevant transmission owner must then assess the generation group to ensure that the transmission system is sufficient in the area to accommodate the existing and proposed generation. Upon completion of the assessment, the ESO will make a formal offer of connection.

2.4.3 The capacity of the transmission system is based on the physical ability of electrical circuits to carry power. Each circuit has a defined capacity and the total capacity of the circuits in a region or across a boundary is the sum of all of the capacity of all the circuits.

2.4.4 The capability of the transmission system is the natural flow of energy that can occur in the infrastructure comprising the network. Due to the physical properties of the transmission system, this is often not as great as the theoretical capacity of the infrastructure in question.

2.4.5 Where power flows are constrained by the transmission system across a specific number of circuits, this is termed a "boundary" by the ESO. Such boundaries are used in the ETYS to identify constraints which may require changes to the transmission system in the next 10 years.

2.4.6 Where capacity and capability of the transmission system are not sufficient, either from a generation group or across a boundary, NGET will be required to reinforce the network. It does this by either modifying the existing network (if possible) and / or constructing additional transmission infrastructure to resolve the shortfall.

[9] Electricity Ten Year Statement, National Grid ESO (2022) https://www.nationalgrideso.com/document/275611/download

2.5 Requirement for changes to the transmission system

2.5.1 Under the terms of the Transmission Licence, NGET is required to provide an efficient, economic and co-ordinated transmission system in England and Wales. The transmission infrastructure needs to be capable of maintaining a minimum level of security of supply and of transporting electricity from and to customers. NGET is required to ensure that its transmission system remains capable as customer requirements change.

2.5.2 The transmission system needs to cater for demand, generation and interconnector changes. Customers can apply to the independent ESO for new or modified connections to the transmission system; The ESO is then required to respond to each customer application with an offer for a new or modified connection.

2.5.3 In line with the Government's 2050 targets, a large volume of applications have been made to the ESO for connection at locations that are more remote from the existing transmission system, or which are in the vicinity of parts of the transmission system that do not have sufficient capacity available for the new connection.

2.5.4 NGET has a key role providing a transmission system which serves all consumers in England and Wales. As a monopoly, NGET is regulated by Ofgem on behalf of consumers and is required to operate in accordance with the Transmission Licence. This includes maintaining reliable electricity supplies and offering to connect new energy suppliers. Where the network needs to be developed to do that, NGET must be efficient, co-ordinated and economical and have regard to the desirability of preserving amenity, in line with the duties under sections 9 and 38 of the Electricity Act.

2.5.5 In developing new network infrastructure proposals, NGET is therefore guided by the legislative and policy framework set by the UK Government. Including requirements set out in the Planning Act 2008 and associated National Policy Statements (NPS) as described in detail in Appendix B.

2.6 ESO role in development of the transmission system

2.6.1 The ESO has annual processes to publish the ETYS, which sets out the network performance and requirements for all transmission in Great Britain over the next 10 years.

2.6.2 The ESO also has annual processes to publish the Future Energy Scenarios[10] (FES) which take a number of energy industry views as part of a consultation process and develop a set of possible energy growth scenarios.

2.6.3 Similarly, it has an annual process to publish the Network Options Assessment[11] (NOA), which considers options for reinforcing the transmission system and makes economic recommendations. This document takes account of the ETYS and FES to establish via a Cost Benefit Analysis (CBA) process when it is right to take forward options proposed by transmission owners to increase network capacity. This considers the capital cost of the proposal, delivery timescales and constraint costs (as explained further below) avoided by delivering the proposal. This establishes when a proposed reinforcement

[10] Future Energy Scenarios, National Grid ESO (2022) https://www.nationalgrideso.com/future-energy/future-energy-scenarios

[11] Network Options Assessment 2021/22 Refresh, National Grid ESO (2022) https://www.nationalgrideso.com/document/262981/download

becomes the most economic, efficient and coordinated way to deliver value to Great Britain's energy consumers.

2.6.4 The ESO manages shortfalls in boundary capacity by reducing power flows and constraining generation. This is achieved by paying generators to reduce their outputs, known as 'constraint costs'. Ultimately, constraint costs are passed on to consumers and businesses through electricity bills.

2.6.5 The ESO published the Holistic Network Design[12] (HND) report in summer 2022. It is now engaged in the HND Follow Up Exercise. The HND sets out a single integrated transmission network design that supports the large scale delivery of electricity generated from offshore wind.

2.6.6 The ESO is also undertaking the Offshore Coordination Project, of which the HND is part. This considers how the transmission network is designed and delivered, to ensure that the transmission connections for offshore wind generation are delivered in the most appropriate way considering the increased ambition for offshore wind to achieve net zero. It considers environmental, social and economic costs.

2.6.7 Subsequent to the ESO reinforcements identified in HND and NOA refresh, Ofgem have published the Accelerated Strategic Transmission Investment (ASTI) decision, which aims to facilitate achieving government targets by streamlining the regulatory approval and funding process for ASTI projects.

[12] National Grid ESO. (2022). Pathway to 2030. A holistic network design to support offshore wind deployment for net zero. National Grid ESO (2022) https://www.nationalgrideso.com/future-energy/pathway-2030-holistic-network-design

3. Reasons why NGET's transmission system needs to develop

3.1 Changes to electricity industry in GB

3.1.1 The electricity industry in Great Britain is undergoing unprecedented change. The Climate Change Act 2008 (as amended) now commits the UK Government by law to reducing greenhouse gas emissions by at least 100% from the 1990 baseline by 2050. This 2050 target is commonly known as 'Net Zero'.

3.1.2 Historically, the transmission system was powered by coal powered generating stations. To achieve Net Zero, there will need to be a substantial shift away from the use of fossil fuel burning generation. Closure of fossil fuel burning generation and end of life nuclear power stations, with more expected to close in the future, means significant additional investment in new generating and interconnection capacity will be needed to ensure existing minimum standards of electricity security and supply are maintained. The investment and legal drivers strengthen the likelihood most planned connections of new generation and interconnection capacity will be progressed to delivery.

3.1.3 Growth in offshore wind generation and interconnectors to Europe has seen a significant number of connections planned in Scotland, England and significantly in areas of the East Coast of England. Investment in low carbon generation is expected to increase further in the future. The Net Zero ambition strengthens the likelihood of most of the planned new connections progressing to delivery.

3.1.4 Generators apply to the ESO for connections to the NETS in Great Britain. If the application is for an onshore generation connection, the applicant will indicate the specific location of the generating station, which will indicate the likely geographical connection to the transmission system. If the application is for an offshore connection or impacts multiple transmission owners, outputs from the ESO's Offshore Coordination project[13] will inform preferred connection option selection decisions.

3.1.5 The ESO ensures the relevant on shore or offshore transmission owner undertakes generation connection process studies via the relevant process and makes a connection offer to the customer for a connection point and identifies the relevant infrastructure work needed to make the connection. Once this offer is signed the connection is recorded on the Transmission Entry Capacity (TEC) Register and forms a contractually binding connection location and timescale with which the transmission owner, such as NGET, is required to connect the generation customer or undertake the works to facilitate their connection.

3.1.6 A connection offer will normally be given in respect of a particular geographical area. Sometimes this leads to a presumption as to the connection point located on the existing transmission network. In other circumstances where there is no or little existing transmission infrastructure, this will require the provision of new infrastructure. The post connection offer assessment process enables further evaluation of the preferred connection option and refinement of the preferred overall transmission solution. This

[13] Offshore Coordination project: https://www.nationalgrideso.com/future-energy/projects/offshore-coordination-project

process continues, informed by evolving circumstances and consultation, until an application is submitted for development consent in relation to a transmission project.

3.1.7 The fossil fuelled and end of life nuclear power stations generating capacity is being replaced by low carbon generation which is at different geographic locations. The transmission system must be updated to meet the needs of generating stations at new locations.

3.1.8 Electricity demand is especially concentrated in large urban areas across Great Britain, including urban areas in the M8 corridor, the M62 corridor, the M18 corridor, the Midlands, the M4 corridor and the Southeast. The transmission system carries bulk energy from the generators to points on the network where that power is taken onto the distribution networks for onward transmission to homes and businesses across England and Wales. As the country decarbonises and fossil fuel usage declines, demand for electrical energy will increase.

3.2 Impact on transmission system of changing user requirements

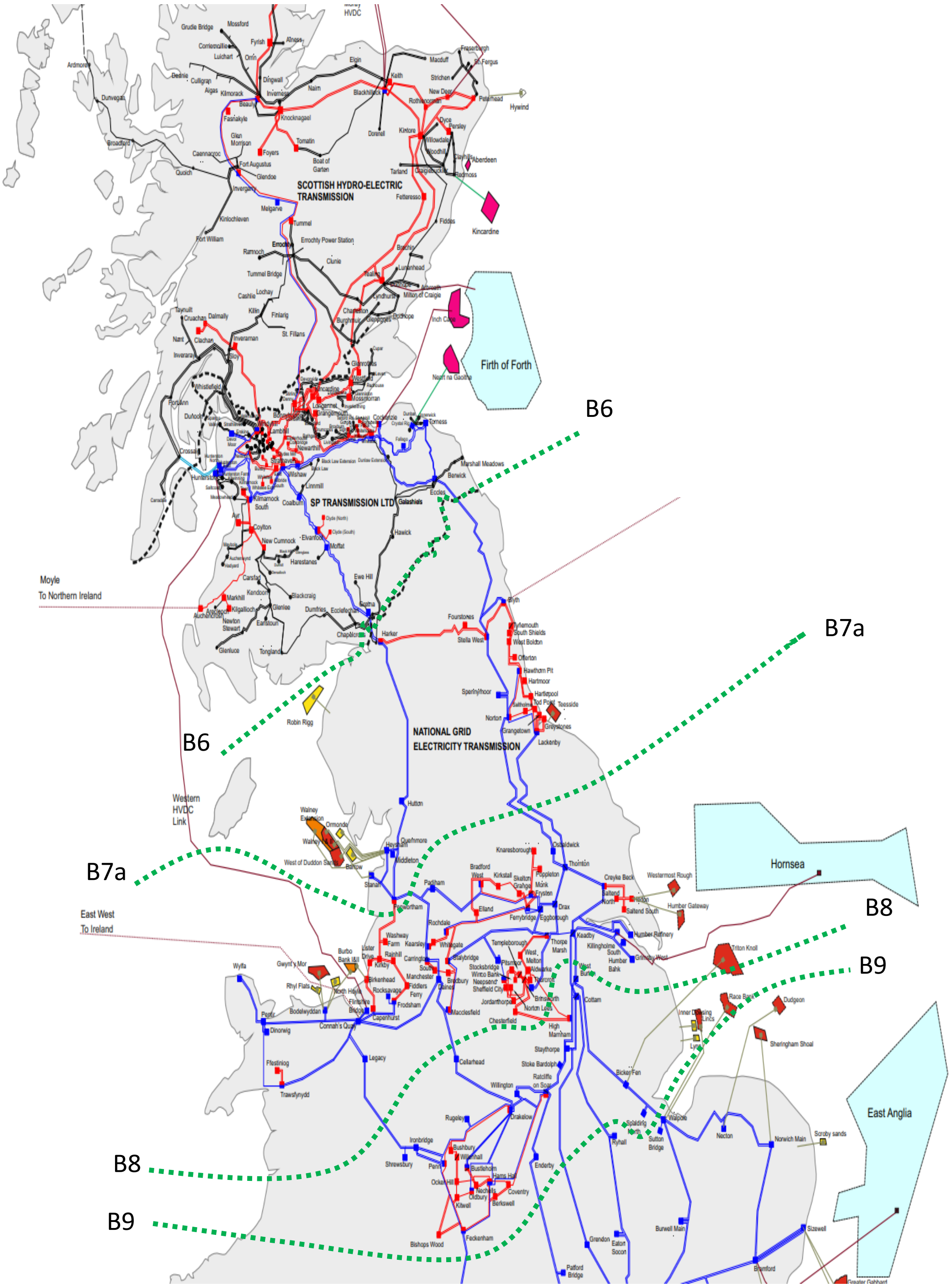
Existing transmission system

3.2.1 The transmission system in the Scotland, North of England and Midlands areas was primarily constructed in the 1960s, at the same time as much of the rest of the transmission system. It was designed to connect coastal, in land large coal fired power stations and nuclear power stations in Scotland, the North and Midlands areas in England. The existing transmission system in Scotland, the North of England and the Midlands is shown in Figure 3.1.

3.2.2 Transmission system changes occurred in the 1990s, in particular to connect gas fired power stations in the Humber region. In some areas within this region, little or no transmission infrastructure was constructed and there is limited ability to support new generator connections on the coast.

3.2.3 The geography under consideration for the EGL3 and EGL4 projects is shown in Figure 3.1:

Figure 3.1 – The National Electricity Transmission System in Scotland, the North of England and the Midlands



3.2.4 The transmission system shown in Figure 3.1 shows system boundaries B6. B7a, B8 and B9. System boundaries are used to help NGET to identify regions where reinforcement is most needed by enabling analysis on a targeted basis. They can be:

- local boundaries, which are small areas of the transmission system with a high concentration of generation, or
- wider system boundaries, which are large areas of the transmission system containing significant amounts of both generation and demand.

3.2.5 System boundary definitions have evolved over many years of planning and operating the transmission system. Each defined system boundary splits the transmission system into two parts and tend to be located at critical circuit paths that carry power between geographic areas, where limitations may be encountered.

3.2.6 Presently, each of these system boundaries where these limitations are defined are:

- between NGET and SPT's transmission systems (B6);
- that bisects England South of Teesside and into the Mersey ring area (B7a);
- that separates Northern generation zones (including Scotland, Northern England and North Wales) and the demand centres in the North and the Midlands (B8), and
- that separates the Midlands demand and generation zones (including all of great Britain north of the Midlands including North Wales) from the demand centres of the South (B9).

3.2.7 Future system boundary requirements are assessed using information from the ESO's FES to identify expected future power flows across relevant system boundaries. Each of the ESO and NGET carry out power system analysis to determine the maximum power flow that can be transferred across a system boundary while compliance with minimum levels of security and quality of supply is maintained.

Minimum standards of security and quality of supply that need to be maintained

3.2.8 NGET must comply with Section 9 of the Electricity Act and Standard Condition D3 (Transmission system security standard and quality of service) of its Transmission Licence. As set out in section 2.5, the transmission system must at all times meet defined level of minimum levels of security and quality of supply. The NETS SQSS defines criteria relevant to:

- the main interconnected transmission system (MITS);
- generations connections, and
- demand connections.

3.2.9 When required power flows are identified that would exceed the boundary capability/capacity of the transmission system, NGET must resolve the capability/capacity shortfall under the terms of its Transmission Licence.

3.2.10 NGET assesses the adequacy of its transmission system in accordance with the method defined in the NETS SQSS. We are required to assess power flows that transfer between regions of the transmission system. The Planned Transfer (the amount of power which will flow out of the region at ACS peak) is calculated from the Average Cold Spell (ACS) Peak Demand and generation in that region, following the modelling approach set out in the NETS SQSS. Planned Transfer calculations will always consider the power flows for ACS peak demand conditions, as less generation will be entering the market when demand is lower.

3.2.11 Any transmission system is susceptible to faults that interfere with the ability of transmission circuits to carry power. Most faults are temporary, e.g. related to weather conditions such as lightning or severe weather, and many circuits can be restored to operation automatically in minutes after a fault. Other faults may be of longer duration and would require repair or replacement of failed electrical equipment.

3.2.12 Whilst some of these faults may be more likely than others, faults may occur at any time, and it would not be acceptable to have a significant interruption to supplies as a result of specified fault conditions, including combinations of faults. The principle underlying the NETS SQSS is that the NETS should have sufficient spare capability or "redundancy" such that fault conditions do not result in widespread supply interruptions. The level of security of supply has been determined to ensure that the risk of supply interruptions is managed to a level that maintains a minimum standard of transmission system performance. The faults we need to design the system to be compliant with are called "Secured Events".

3.2.13 The NETS SQSS defines the performance required of the NETS in terms of quality and security of supply for secured events that at all times:

- Electricity system frequency should be maintained within statutory limits;
- No part of the NETS should be overloaded beyond its capability;
- Voltage performance should be within acceptable statutory limits; and
- The system should remain electrically stable.

3.3 Recommendations provided by ESO

3.3.1 As part of an annual NOA process, the independent ESO assesses the capital cost of options provided, delivery timescales, and constraint costs avoided by increasing capacity.

3.3.2 The NOA provides the ESO recommendation relating to which reinforcement projects should receive investment for the next financial year. The NOA reports play an important role in indicating the ESO's view of options and timescales required to meet system needs. However, NGET has responsibility for investment decisions including the development and appraisal of specific design options.

3.3.3 The ESO publishes findings of its independent evaluation of the performance of the NETS and provides in:

- ETYS publications (which are updated at least annually), the ESO's view of future transmission requirements and the capability of the NETS over the next ten years;
- FES publications (which are updated at least annually), a range of possible future energy scenarios;
- NOA publications (which are updated at least annually), a range of recommendations for transmission system development required for expected changes to transmission usage, and
- the HND publication, holistic network design solutions intended to facilitate a more integrated approach to transmission system development.

3.3.4 The ESO recommended multiple East Coast onshore and offshore reinforcement developments as part of the 2018/19 NOA. ESO recommendations are subject to ongoing review and further updates were reported in the 2019/20 and 2020/21 NOA reports.

3.3.5 As part of the ESO evaluation process to produce the NOA, NGET is required, as part of any options appraisal, to produce a high level scope that sets out an indicative construction delivery date and estimated capital costs for all of the options proposed. The ESO also requires us to explain the expected impact of each proposed option on boundary capability. The ESO use this information as part of their CBA process, which identifies any variance in benefit to consumers across options, based upon estimated constraint costs. The outcome of the CBA is reflected in the regular NOA publication with a proceed signal against recommended investments.

3.3.6 The 2021 ETYS set out that without transmission system reinforcement, each of system boundaries B6, B8 and B7a would be significantly constrained by 2030 with insufficient capability to meet the NETS SQSS requirements.

3.3.7 The 2021/22 NOA recommended that network reinforcements should be developed to resolve the issues associated with system boundaries B6, B7a and B8 that were identified in the 2021 ETYS. These recommendations referred to the construction of two new 2GW subsea HVDC circuits on the East Coast between Scotland and England, a new subsea HVDC circuit between Peterhead and the South Humber region, a new subsea HVDC circuit between south east Scotland (subsequently confirmed to be Fife) and the South Humber region. These new HVDC circuits, are part of the continued coordinated development of significant cross-border transmission routes that is needed due to the significant and increasing levels of North-South power flows.

3.3.8 Details of the ESO assessment of options for connections across the B6 and B7a system boundaries are set out in the July 2022 HND report[14]. The ESO presented design recommendations in respect of the need[15] to reinforce the B6 and B7a boundaries that was current when the HND report was published. A key part of the HND design recommendation to partially resolve issues at the B6 and B7a system boundaries, was the connection of two new HVDC subsea links between eastern Scotland and the south Humber area, with further reinforcements being required to address the deficit.

3.3.9 For the B6, B7a, B8 and B9 system boundaries, the requirements for the majority of conditions set out in the ESO's FES (90% of conditions across all four scenarios), show boundary export levels by 2030 in the range of:

- 17,416MW to 25,546MW for the B6 system boundary;
- 17,262MW to 28,473MW for the B7a system boundary;
- 18,100MW to 28,929 MW for the B8 system boundary and
- 13,902 MW to 23,330 MW for the B9 system boundary.

3.3.10 It is noted that one of the scenarios presented in the FES (Falling Short) would not achieve the 2030 Net Zero target and represents the lower end of the 90% range.

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[14] The Holistic Network Design report: https://www.nationalgrideso.com/future-energy/pathway-2030-holistic-network-design/holistic-network-design-offshore-wind

[15] The need for development of B6 and B7a system boundaries was included as part of the ESO's 2016/17 NOA publication.

3.3.11 There is currently a high volume of transmission system development ESO recommendations within Scotland, the North of England and the Midlands regions. These NOA recommendations reflect the network design recommendation provided in the HND. The ESO's NOA 2021/22 Refresh report currently indicates proceed signals for six investment proposals in the south Humber area that could interact.

3.3.12 The associated ESO NOA code and descriptions of the other investment proposals with proceed signals are:

- (NOA code EDEU) Proceed - 400 kV upgrade of Brinsworth to Chesterfield and Chesterfield to High Marnham double circuit 275kV lines including development of new High Marnham and Chesterfield 400 kV substations (earliest optimal delivery date 2028);
- (NOA Code E4L5) Eastern Scotland to England 3rd link: Peterhead to the south Humber subsea HVDC Link (earliest optimal delivery date 2030);
- (NOA Code TGDC) Eastern subsea HVDC Link from east Scotland to south Humber area (earliest optimal delivery date 2030);
- (NOA code CGNC) Proceed - new 400 kV double circuit between Creyke Beck and the south Humber region (earliest optimal delivery date 2030);
- (NOA Code GWNC) Proceed - new 400 kV double circuit between south Humber and south Lincolnshire (earliest optimal delivery date 2030), and
- (NOA Code LRN4) Proceed - new network need from North Lincolnshire to Hertfordshire (earliest optimal delivery date 2030).

3.3.13 As well as restating recommendations to develop two new East Coast HVDC links, the ESO's NOA 2021/22 update document also advised of an earlier optimal delivery date of 2030 for each of these new HVDC links.

3.3.14 The ESO's NOA 2021/22 Refresh report identifies a further investment proposal in the East of England area (NOA Code WWNC) - new South Lincolnshire to East Anglia double circuit (earliest optimal delivery date 2033). The ESO has provided a hold signal for this recommendation, reflecting the need for further analysis work by each of the ESO and NGET to determine the best date that the reinforcement is needed.

3.3.15 Recommended transmission system developments LRN4 and WWNC would be expected to provide the additional capability at the B9 system boundary identified as required. These recommendations were based on an assumption informed by the HND, that 2 new HVDC links from Scotland (NOA codes E4L5 and TGDC) would connect in the South Humber area.

4. EGL3 and EGL4 Need Case (applicable at date of this report)

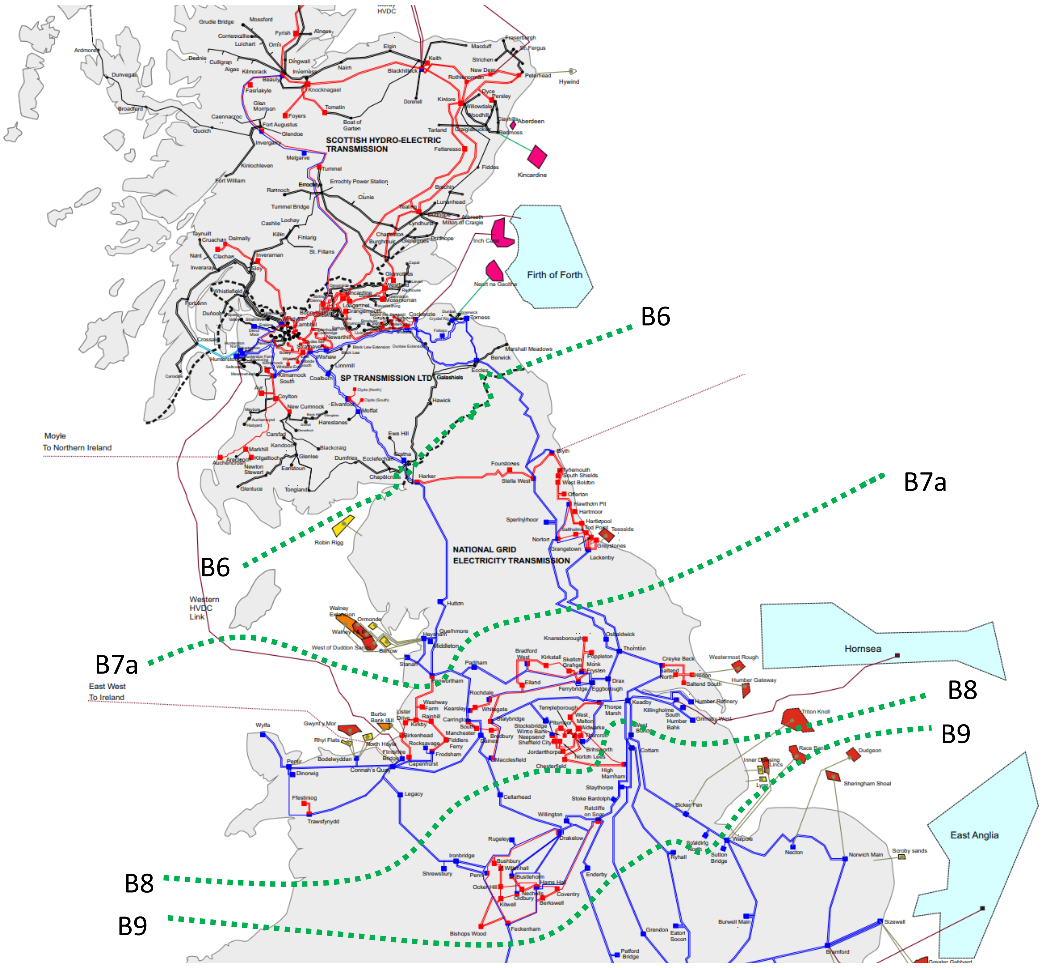
4.1 Introduction

4.1.1 As part of NGET's assessment of the ESO's recommendation to connect two 2GW HVDC links to the transmission system in the South Humber area, we carried out computer-based analysis to evaluate the impact on our existing transmission system. This section provides an overview of the results from NGET's analysis and explains the need for transmission system reinforcement that has been identified to accommodate these two new connections.

4.2 NGET's analysis

4.2.1 The geography under consideration for the projects is shown in Figure 4.1:

Figure 4.1 – The National Electricity Transmission System in Scotland, the North of England and the Midlands



4.2.2 NGET has evaluated the B6, B7a, B8 and B9 system boundaries using the Economy Planned Transfer assessment (defined in the NETS SQSS), which takes prescribed generation contributions from above and below the boundary, alongside demand in each area to determine the expected flow across the system boundary. In this case the Economy Planned Transfer condition represents the most onerous system boundary condition which must be secured by NGET to meet the requirements set out in the NETS SQSS.

4.2.3 Studies have been undertaken to assess the impact of changes in demand and generation on power flows across each of these boundaries, to determine if these impacts require reinforcement to the transmission system.

4.2.4 The capacity during the winter ACS period of each of the circuits which cross the B6, B7a, B8 and B9 system boundaries is known. The sum of the capacity for all of these circuits provides the pre fault capacity.

4.2.5 The post fault capacity is defined by the remaining capacity across a boundary following the worst case fault condition (secured event). Following a secured event, each system boundary then will see flows across it based upon the circuit parameters and system conditions, when the natural flow of energy on every circuit will be maximised. This is known as the circuit boundary capability, which is based upon the capability seen following the secured event.

4.2.6 Table 4.1 shows the capacities and capabilities applicable to system boundaries B6, B7a, B8 and B9 in 2030 without reinforcement of the existing transmission system:

Table 4.1 – Existing transmission system capacities and capabilities by 2030

System Boundary	Pre Fault Capacity	Post Fault Capacity	Post Fault Capability
	MW	MW	MW
B6	18,263	11,611	11,500
B7a	20,459	15,623	13,400
B8	23,351	17,426	14,000
B9	24,411	18,033	13,700

4.2.7 In line with the recommendation from the ESO and for the purposes of the initial power system analysis, it was assumed that each of EGL3 and EGL4 would be connected to NGET’s transmission system in the South Humber area.

4.2.8 Table 4.2 below shows how the existing system boundaries perform in 2030, for the expected planned transfer flows.

Table 4.2 – Existing system boundary performance by 2030 (to last contract date)

System Boundary Export		Pre 2030 Post Fault Capability	Pre 2030 Post Fault Capacity	Capability Deficit	Capacity Deficit	Secured Event Fault
B6 – 2030 (system boundary)	21,760 MW	11,500 MW	11,611 MW	**-10,260 MW**	**-10,149 MW**	Stella West – Eccles double circuit
B7a – 2030 (system boundary)	23,754 MW	13,400 MW	15,623 MW	**-10,354 MW**	**-8,131 MW**	Lackenby - Thornton Double Circuit
B8 – 2030 (system boundary)	24,632 MW	14,000 MW	17,426 MW	**-10,632 MW**	**-7,206 MW**	Keadby – West Burton 400kV double circuit
B9 – 2030 (system boundary)	19,570 MW	13,700 MW	18,033 MW	**-5,870 MW**	**-1,537 MW**	Walpole – Bicker Fen/Spalding 400kV double circuit

4.2.9 The system boundary assessments completed on the Economy Planned Transfer already account for generation contribution. To ensure representative need for reinforcement, NGET has taken the average requirements to cover 90% of operating conditions of the System Transformation, Consumer Transformation and Leading the Way scenarios (set out in the ESO's FES 2022). These are the scenarios that meet the government's 2050 net zero ambition. Against this highly likely requirement, clearly there is a shortfall against system boundary capability and capacity, for each of the B6, B7a, B8 and B9 system boundaries.

4.2.10 In all cases it is clear even if flows could be maximised across the system boundary for fault secured events, the boundary capacity would be exceeded at all boundaries shown in Table 3.2. Boundary capacity is the physical maximum power that can be transferred across the existing physical boundary (i.e. without carrying out reinforcement work to increase capacity). Large boundary capacity deficits were identified for the B6, B7a, B8 and B9 system boundaries, which define the need case for this report.

4.2.11 From 2030 further increases in system boundary requirements are expected and this is reflected in NGET's existing contractual commitments. To address these needs, additional reinforcements are expected in Central England and Wales which will supplement these system boundaries in the future. This will facilitate connections beyond 2030 when further increases in generation are expected in all regions, which will be subject to their own detailed need case and options assessment. Any future requirements would be informed by further need case assessments and option appraisals. These emerging requirements do not affect the need case set out within this report.

4.3 Managing impacts of interactions with other developing transmission system reinforcement proposals

4.3.1 NGET has identified specific requirements to reinforce the B6, B7a, B8 and B9 system boundaries as part of the need case set out in this report. The analysis carried out took account of changes to the contracted background and the user connections expected in 2030.

4.3.2 Due to the volume of changes being sought within this geographic region currently, the analysis was not able to take account of transmission changes that may be identified, proposed and/or delivered before 2030. For analysis purposes, NGET takes account of:

- existing transmission system plant and equipment, and
- planned changes to the transmission system that have been consented or are within scope of existing permissions.

4.3.3 Each of NGET's investment proposals is subject to its own set of detailed analysis and assessments. In areas with multiple transmission system change requirements which impact on the same system boundaries, NGET also considers possible impacts of interaction between proposals that are being developed, but consents have not yet been applied for.

NGET's transmission system development proposals that impact on system boundaries B6, B7a, B8 and/or B9.

4.3.4 The need case for two of NGET's current projects:

- North Humber to High Marnham
- Grimsby to Walpole

sets out a requirement for reinforcement of the B8 and B9 system boundaries.

4.3.5 NGET has progressed these projects to the next development stage and in May 2023 consulted on possible strategic options for the required transmission system reinforcements within the North Humber to High Marnham and Grimsby to Walpole Strategic Options Report[16]. If developed, these projects would provide sufficient capacity across the B8 and B9 system boundaries for the connection to NGET's transmission system of groups of:

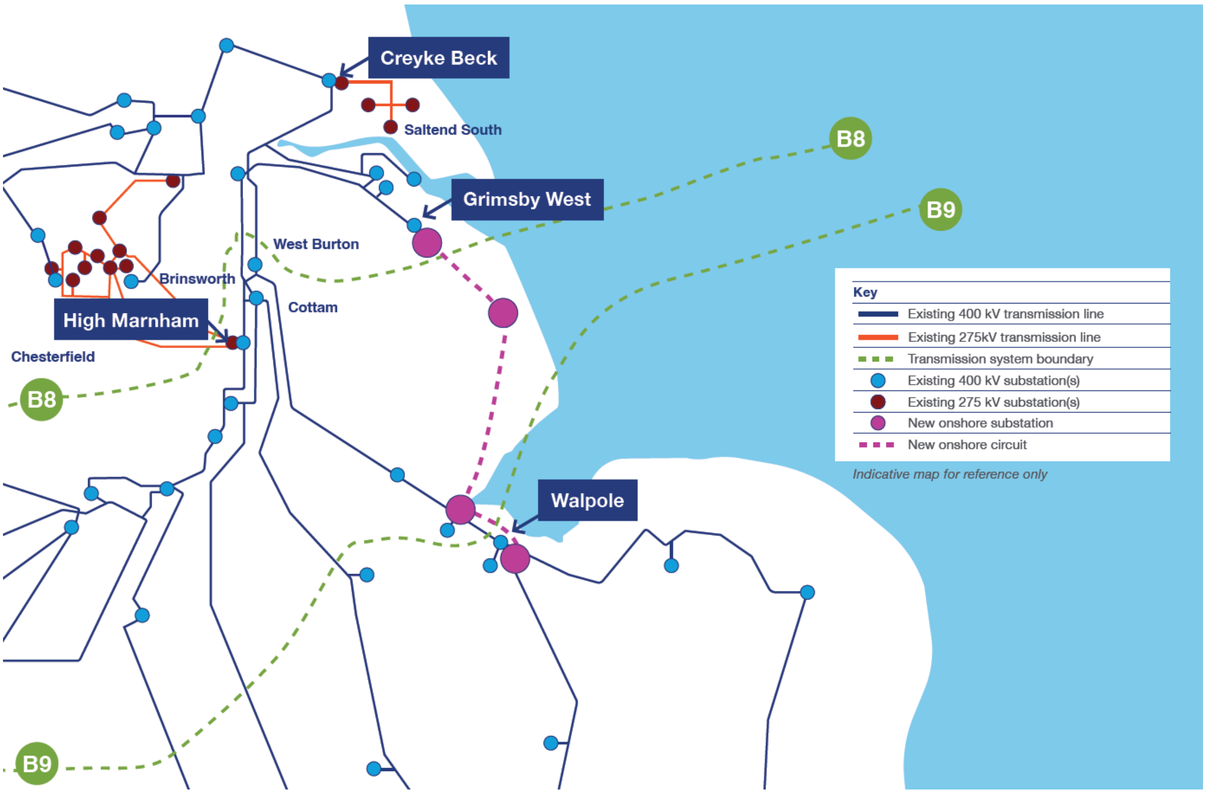
- generation within the Creyke Beck area, and
- generation and interconnectors within the area south of the Humber Estuary and north of the Wash

for the contracted position, as well as providing capacity for future generation connections in these areas.

[16] NGET's North Humber to High Marnham and Grimsby to Walpole Strategic Options Report https://www.nationalgrid.com/electricity-transmission/document/149041/download

4.3.6 These projects are illustrated in figure 4.2 below:

Figure 4.2 : NGET's North Humber to High Marnham and Grimsby to Walpole projects



4.3.7 It is noted that if the:

- North Humber to High Marnham project is progressed, a new High Marnham substation would need to be established
- Grimsby to Walpole project is progressed new Walpole, Grimsby West and Lincolnshire Connections Node substations would need to be established.

4.3.8 NGET made an assessment of the possible interactions between the North Humber to High Marnham and the Grimsby to Walpole projects and the developing proposals for the connection of the two new 2GW HVDC links from Scotland in the South Humber area. Results from that assessment were reported as part of the North Humber to High Marnham and Grimsby to Walpole Strategic Options Report.

4.3.9 A key conclusion from NGET's previous interactivity assessment work is that the connection locations selected for the two new HVDC links with Scotland, significantly impact on the volume of changes that are required in the Lincolnshire region.

4.3.10 Looking at holistic benefits to all projects, one outcome (from the previous interactivity assessment), was an NGET recommendation that the scope of the options appraisal for EGL3 and EGL4, should consider options for connecting both new HVDC links to a MITS substation south of the B9 boundary. The connection is required at a Main Interconnected Transmission System (MITS) substation. A MITS substation has more than two double circuits connected to it. I this case provided benefit, because more than two circuits south of the connection point are required to provide benefit to the B9 boundary. This ensures that under fault conditions energy can flow to the south of the connection location.

Noting that this NGET recommendation would be expected to provide increased boundary capacity (and potentially reduce the deficit levels identified in the North Humber to High Marnham and Grimsby to Walpole Strategic Options Report meaning that these proposed reinforcement would be sufficient without additional infrastructure to meet the need), NGET extended the scope of its analysis for EGL3 and EGL4 to include assessment of options that would connect the two new HVDC links south of the B9 system boundary.

5. Identification of Potential Strategic Options

5.1 Introduction

5.1.1 When a need to reinforce the NETS is established, NGET brings together a multi-disciplinary scheme team to evaluate a wide range of options. This team produces a list of potential strategic options which can be further refined through evaluation processes and which are described within this report.

5.1.2 The project team keeps the options under review, for example as changes to the drivers emerge as a consequence of interactions with other projects. Through this review, potential strategic options can be modified or deselected and new ones can be added.

5.1.3 The analysis for the need case set out in this report was based on the recommendation made by the ESO to connect the new HVDC links to NGET's transmission system in the South Humber area. The results from NGET's analysis of the power flows expected in 2030, highlighted capacity deficits across the B6, B7a, B8 and B9 system boundaries. These drivers for reinforcement of the transmission system, are set out in section 4 of this report.

5.0 Review of recommended technology option

5.0.0 Following the ESO recommendations for the connection of two new HVDC links in the South Humber area, we considered currently available alternative technology options which could be used to address the identified need for additional transmission system capacity to accommodate increased north-south power flows. As part of this review, we considered whether AC based onshore options using overhead line technology solutions to meet the identified requirement, should be further investigated.

5.0.1 The largest capacity AC technology option that can be used on NGET's transmission system consists of two 3,465 MW transmission circuits that are supported on a single set of towers (6930 MW double circuit capacity). The largest HVDC capacity systems that can currently be accommodated on our transmission system are 2,000 MW HVDC cables.

5.0.2 Power flows on AC transmission system circuits cannot be controlled to the same extent as can be achieved using HVDC connections. This lower level of controllability can result in higher power flows particularly during transmission system fault conditions. Taking account of the potential for higher power flows that could be expected, therefore to provide the potential equivalent capacity, the AC option would need to consist of a high capacity (6,930MW) double circuit route to meet any high loading during fault conditions.

5.0.3 The required capacity HVDC links over the proposed distance have comparable capital costs, but much lower lifetime costs than the alternative onshore AC option in this case. It is also recognised that delivery of an onshore solution with a long route length, carries much higher delivery risk than the HVDC reinforcement proposals (EGL3 and EGL4) that are currently being progressed. The use of overhead lines is not considered to be feasible because they cannot be delivered by the required 2030 timescale. Consequently, an option using overhead line technology is not considered to meet the identified need for additional transmission system capacity and therefore, was discounted.

5.0.4 Further details of NGET's initial evaluation of this onshore alternative option is provided in Appendix F.

5.1 Identification of Potential Strategic Options

5.1.0 NGET has published "Our Approach to Consenting" which sets out how we develop our strategic proposal. We apply the following approach to evaluate options we take forward.

5.1.1 Firstly, we identify if our existing network could be modified or enhanced to deliver the required connection or increase in capacity. Limiting factors on transmission capacity include thermal circuit rating, voltage constraints, and dynamic stability.

5.1.2 If we identify there is a need that is beyond the capability of our existing network, as is clearly set out in the need case for the EGL3 and EGL4 projects, we consider potential strategic options to provide the required increase in capacity.

5.1.3 We apply a technical filter as part of this assessment to ensure any potential strategic option identified meets the need case, either individually or as part of a wider group of reinforcements.

5.1.4 There are many ways to achieve increases to our network capability. To allow us to focus on those that best meet our obligations to the environment and consumers we apply a "benefits filter", which ensures any option we present has a comparable benefit over an alternative. The criteria for an option to be considered are any of the following:

- environmental benefit;
- technical system benefit; or
- capital and lifetime cost benefit.

5.1.5 Where options are very closely aligned across benefits, then options will be included for appraisal to ensure we capture possible solutions that are of very similar capability.

5.2 Identification of Potential Strategic Options for EGL3 and EGL4

5.2.1 Project team members produced a long list of options where each of the new 2GW subsea HVDC circuits could be connected to NGET's existing transmission system on or near to the east coast.

5.2.2 This long list of options included connection points at (or close to) existing (or already planned) NGET substations at Blyth, Stella West, Tynemouth, South Shields, West Boldon, Offerton, Hawthorn Pit, Spennymoor, Hartmoor, Teesside, Hartlepool, Norton, Saltholme, Tod Point, Grangetown, Greystones A, Lackenby, Osbaldwick, Thornton, Creyke Beck, Eggborough, Drax, Saltend South, Saltend North, Hedon, Keadby, Killingholme, Humber Refinery, South Humber Bank, Grimsby West, West Burton, Cottam, High Marnham, Bicker Fen, Spalding North, Weston Marsh, Lincolnshire Coastal Node and Walpole.

Application of technical filter

5.2.3 Any connection point at an existing 275kV substation would require extensive upgrades to the existing transmission system to ensure that NETS SQSS compliance is maintained. Taking account of the additional works that would be required, none of these options would provide substantive benefits compared to other identified connection point options. The 275kV connection point options that were discounted, include Tynemouth, South Shields, West Boldon, Offerton, Hartmoor, Teesside, Hartlepool, Saltholme, Tod Point, Grangetown, Greystones, Saltend South, Saltend North and Hedon substations.

5.2.4 NGET is currently progressing transmission system changes that are necessary for the connection of new generators and interconnectors that have contracted with the ESO. Connection of either 2GW HVDC link at Blyth, Lackenby, Creyke Beck, Humber Refinery, South Humber Bank, Norton or Killingholme substations would require wider works elsewhere on the NETS. Taking account of the additional works that would be required to ensure that NETS SQSS compliance is maintained, none of these options would provide substantive benefits compared to other of the identified connection point options and therefore were discounted.

5.2.5 The recommendation from the ESO was for EGL 3 and 4 to connect in the South Humber area. From the long list identified and following the application of NGET's technical filter, the only connection point within the South Humber area would be at (or near to) Grimsby West substation. Taking account of the recommendation from the North Humber to High Marnham and Grimsby to Walpole projects, the impact that connection of two new HVDC links in the Grimsby West area would be expected to have, was investigated. Connection of either 2GW HVDC link in the Grimsby West substation area would require wider works elsewhere on the NETS. Taking account of the additional works that would be required to ensure that NETS SQSS compliance is maintained and that this option would not provide substantive benefits compared to other of the identified connection point options this option was discounted.

Potential Strategic Options

5.2.6 Through this options identification process, we identified the following potential strategic options for the connection of either or both of the new 2GW HVDC links at (or close to) NGET substations (existing or already planned) at:

- West Burton
- Cottam
- Bicker Fen
- Weston Marsh
- Lincolnshire Connection substation(s)[17]
- Walpole.

5.2.7 Six potential strategic options were taken forward to appraisal.

[17] Development of the new Lincolnshire Connections substation(s) forms part of the preferred strategic option for NGET's Grimsby – Walpole project (ECO5).

6. Appraisal of Potential Strategic Options

6.1 Introduction

6.1.1 All options taken forward for appraisal at this development stage are evaluated in respect of environmental constraints, socio-economic effects, technology alternatives, capital and lifetime costs. The results from NGET's option appraisal assessments at this development stage, are generally published as part of a Strategic Options report. Publication informs stakeholders of how NGET judgments are made in accordance with our legal duties, balancing relevant factors.

6.1.2 In this appraisal, all options are considered using information appropriate to this stage of their development on the assumption that they are deliverable in a reasonable timescale.

6.1.3 Strategic options are identified at a very high level as being electrical solutions between geographic points. Therefore, the potential circuit lengths are derived by taking a straight line distance between the points and adding 20% to accommodate potential route deviations that might be required if the route proceeds forward to more detailed routeing and siting.

6.1.4 All the options were appraised for the purposes of identifying an initial preferred option:

- for NGET's transmission system development proposals and
- to provide relevant information as inputs needed for the ESO's CBA process.

6.1.5 Constraint cost evaluation is carried out by the ESO and is captured in their independent CBA process and is regularly evaluated and reported in NOA publications.

6.2 NGET's option appraisal process

6.2.1 NGET's option appraisal process considers the following areas:

- Environmental assessment topics which consider whether there are environmental constraints or issues of sufficient importance to influence decision making at a strategic level, having particular regard for internationally or nationally important receptors.
- Socio-economic topics which consider whether there are socio-economic constraints or issues of sufficient importance to influence decision making at a strategic level, having particular regard for internationally or nationally important receptors.
- Technical impacts including whether the option would offer particular system benefits over alternatives, introduce any unnecessary system complexity, or cause system operability issues.
- Capital and lifetime costs considers a range of factors, which are listed below;
  - Capital cost of the substation and wider works
  - Capital cost of the circuit costs for each technology appraised
  - Circuit lifetime costs, including circuit capital cost, cost of loses over 40 years and cost of operation over 40 years.

6.2.2 At the initial appraisal stage, NGET prepares indicative estimates of the capital costs. These indicative estimates are based on the high level scope of works defined for each strategic option in respect of each technology option that is considered to be feasible. As these estimates are prepared before detailed design work has been carried out, NGET makes equivalent assumptions for each option. Final project costs for any solution taken forward following detailed design, consenting and risk mitigation will be in excess of any high level appraisal cost. However, all options would incur these increases proportional to initial estimate in the development of a detailed solution. This methodology ensures that all options for appraisal proposes are compared on a like for like basis.

6.2.3 When considering each strategic option, NGET provides circuit cost information for the following technology options for all land based options:

- 400 kV AC overhead line
- 400 kV AC underground cable
- 400 kV AC gas insulated line (GIL)
- 525 kV HVDC underground cable and converter stations

6.2.4 When considering each strategic option, we provide circuit cost information for the following technology options for all subsea based options:

- 400 kV AC subsea cable
- 525 kV HVDC subsea cable and converter stations

6.2.5 A full evaluation of technologies and costs used in our assessments can be found in Appendix D (Strategic options technical appendix 2020/2021 price base) of this report.

6.2.6 We appraise each option for environmental and socio-economic impact, considering a minimum 20 km study area around the strategic option identified. This was done to ensure we understood the main consequences of selecting each strategic option. This meant we could identify the potential impacts and make comparisons between the options. The study areas used to appraise the environmental and socio-economic impacts of options are illustrated in Appendix G.

6.2.7 Timescales and deliverability would only be considered further in the options appraisal process should they become differentiating factors in the selection of the option that best meets our environmental and legal obligations. If these issues of delivery timescales and risk do become differentiating factors in selection of an option, the issue would be set out clearly in the options conclusion. If it is not differentiating, the factor will not be considered further at this assessment stage.

6.2.8 It should be noted that projects which have the shortest delivery timescales will have advantages over those that deliver in longer timescales. Provision of capacity at the earliest opportunity can provide benefit by avoiding constraint costs.

6.3 Appraisal of potential strategic options for EGL3 and EGL4

6.3.1 NGET has identified a requirement for transmission system reinforcement to resolve the NETS SQSS compliance issues set out in section 4 (the EGL3 and EGL4 need case).

6.3.2 At this initial stage, potential landfalls on the Lincolnshire coastline for the new HVDC circuits, were assessed to confirm that feasible opportunities exist. Three potential areas for landfall were identified. Each potential strategic option detailed in this report, has a defined potential landfall and connection point.

6.3.3 Based on this analysis, NGET identified that

- B6, B7a and B8 system boundaries require reinforcements which would deliver >10 GW boundary capability, and the
- B9 system boundary will require reinforcements which would deliver >6 GW of boundary capability).

6.3.4 If the North Humber to High Marnham and Grimsby to Walpole projects are progressed, the additional capacity that would be delivered across system boundaries B8 and B9 would not be sufficient for EGL3 and EGL4 to be connected above system boundary 9 without further transmission system reinforcement. Details of the relevant ESO recommendations (NOA Codes LRN4 and WWNC) are set out in section 3 of this report.

6.3.5 Five of the six identified potential strategic options (EGL OPP1 to 5) are below the B8 system boundary. However, in line with the recommendation from the North Humber to High Marnham and Grimsby to Walpole Strategic Options Report, one of the identified connection locations (the new Walpole substation) is also below the B9 system boundary.

6.3.6 As not all of the potential strategic options are located between the same system boundaries, the applicability of identified boundary flow NETS SQSS compliance issues were considered in two parts:

- Part 1: Provision of >10GW of capacity across the B6, B7a and B8 system boundaries
- Part 2: Provision of >6GW of Capacity across the B9 system boundary to provide resilience for future generation growth

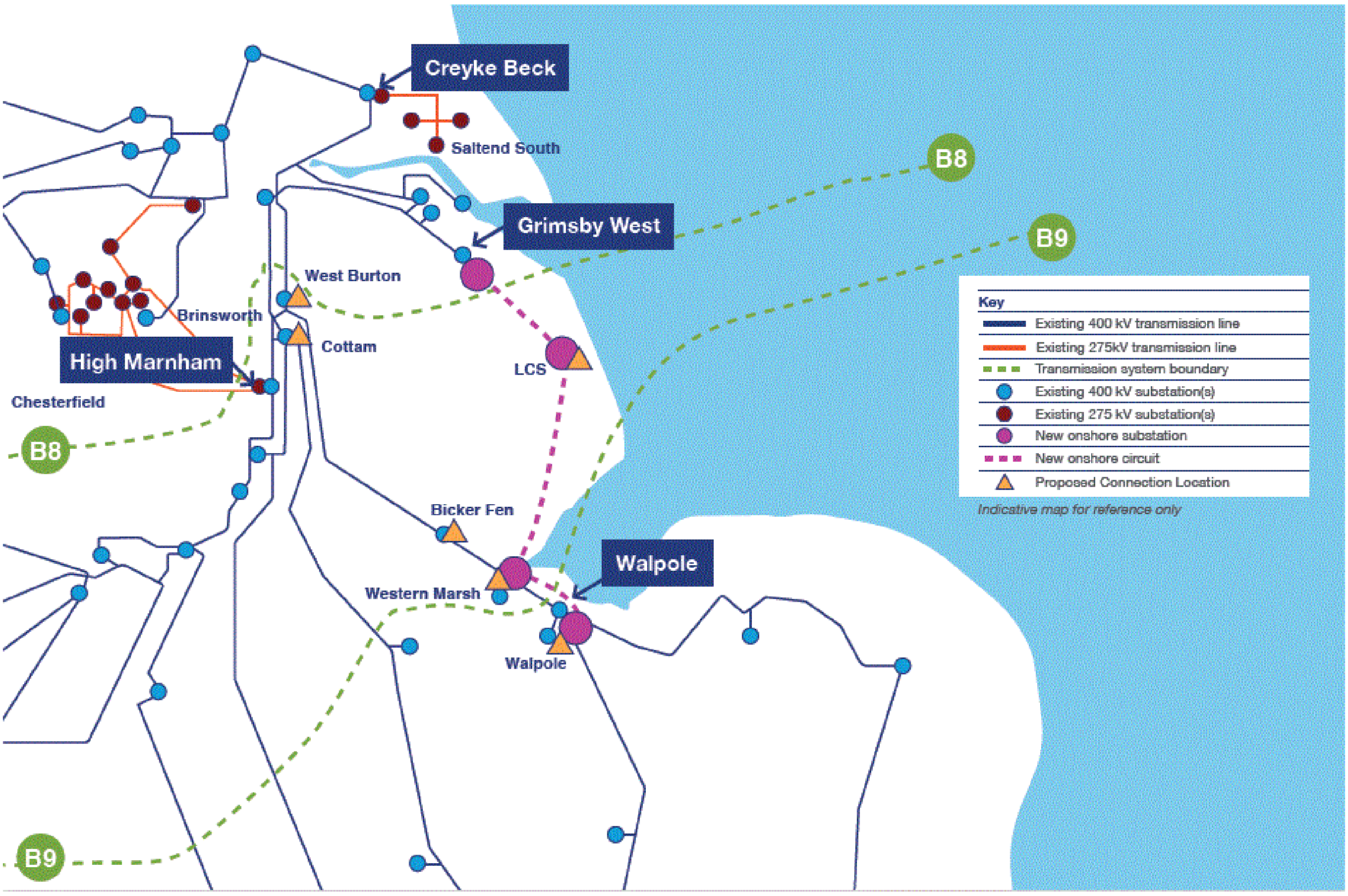
6.3.7 The following potential strategic options for EGL3 and EGL4 were appraised:

- EGL OPP1 - West Burton substation
- EGL OPP 2 - Cottam substation
- EGL OPP3 - Bicker Fen substation
- EGL OPP4 - new Weston Marsh substation
- EGL OPP5 - new Lincolnshire Connection substation(s)
- EGL OPP6 - new Walpole substation
- EGL OPP7 - new Walpole substation (3 Ended Link)

NGET is currently considering the development of the new substations (listed above) as part of our Grimsby to Walpole project.

6.3.8 Figure 6.1 below shows a diagram of the potential strategic options considered within this report:

Figure 6.1– Indicative map of strategic options considered



6.3.9 Where deemed appropriate, a substation designated as "New" has been assigned, for the purposes of this appraisal) an optimal closest existing substation for the purposes of identification. These substations will be subject to a detailed siting assessment should an option be selected.

6.3.10 As an example, the B9 system boundary is defined as cutting the circuits between Spalding North substation and the existing Walpole substation. A new Walpole substation could be sited anywhere along that bisecting circuit, south of the Spalding North circuit tee and west of the existing Walpole substation, to meet the need of crossing the B9 system boundary and providing required capacity.

6.4 Strategic options overview

6.4.1 The following sections provide results from the full strategic options appraisal for each of EGL OPP1 to 7.

6.4.2 System boundaries B6 and B7a, which require a >10GW increase of capacity, will be supported by EGL3 and EGL4 crossing them, providing 4GW of the required capacity. However, the additional 6GW of shortfall across this system boundary is supported by proposals that are set out in the ESO's HND which are outside the scope of this report.

6.4.3 An evaluation of an onshore option for the preferred strategic option identified was made and is included as Appendix F to this report for completeness.

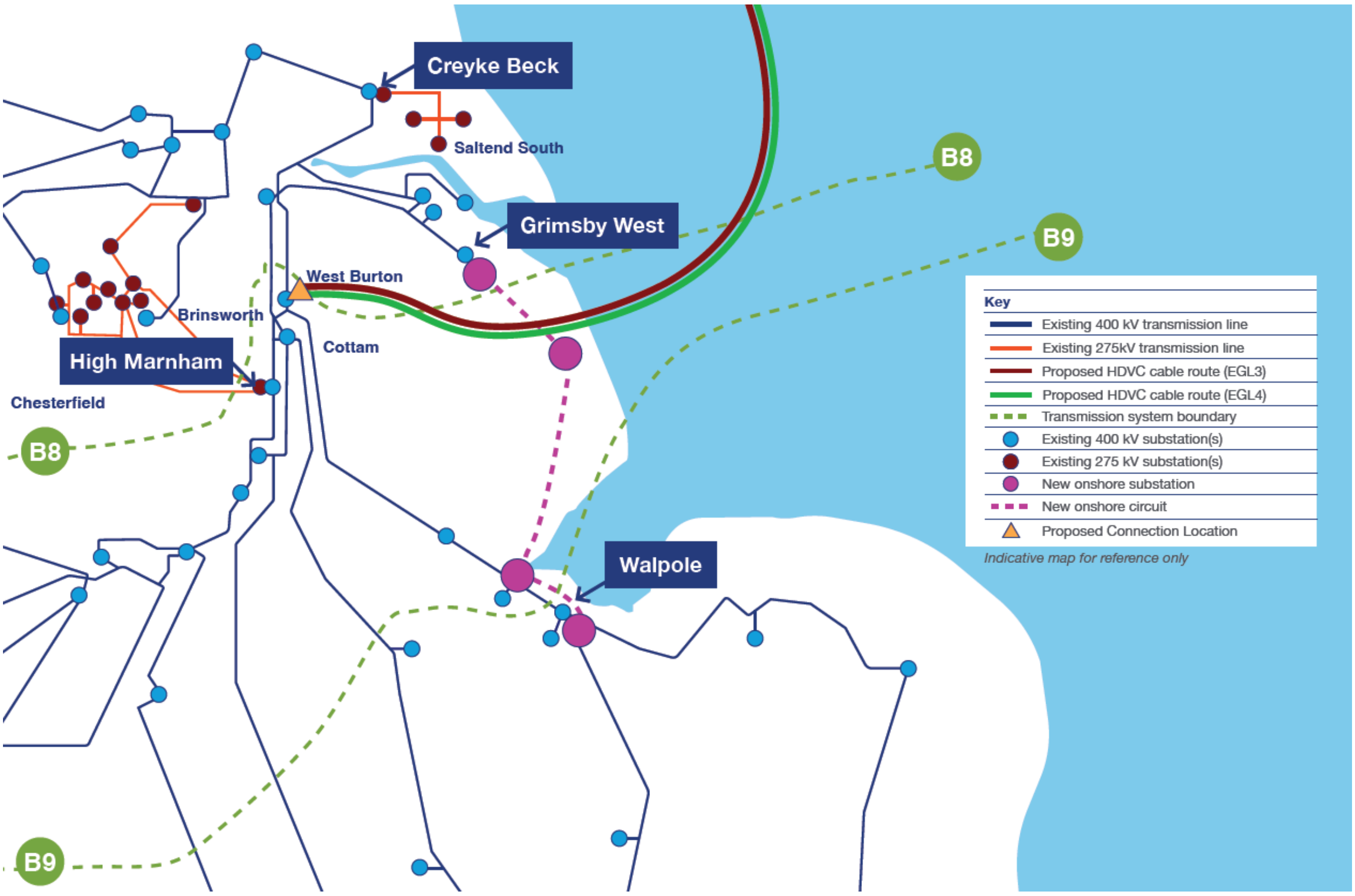
7. Appraisal of potential strategic option EGL OPP1 West Burton substation

7.1 Overview of EGL OPP1

7.1.1 Option EGL OPP1 involves the development of new transmission circuits from Peterhead, Aberdeenshire (EGL3) and Westfield, Fife (EGL4) connecting to the existing West Burton substation in Nottinghamshire. The majority of the new circuits would be routed within the North Sea making landfall on the Lincolnshire coastline between the Humber and the Wash. The marine element of EGL OPP1 is common to all strategic options with the main difference being where the landfall is located (i.e. how far south the submarine cables are routed).

7.1.2 Figure 7.1 below shows a diagram of the location of the EGL OPP1 West Burton potential strategic option considered within this report.

Figure 7.1 – EGL OPP1 West Burton potential strategic option



7.1.3 The circuit distances for this connection are set out below. These are based on subsea cable route distances from a preliminary cable routeing study and the longest straight-line distance from a landfall on the Lincolnshire coastline to the existing West Burton substation.

- EGL 3 - 625km
- EGL 4 - 521km
- Total combined distance 1146km

7.1.4 This option is formed of two HVDC links which would require two pairs of two HVDC cables (i.e. 4 cables in total) as well as converter stations at either end of the links (one in Peterhead, one in Westfield and two converter stations at West Burton). This option would require two converter stations with an approximate footprint of 6 ha each (an indicative diagram is provided in Appendix C) as well as onshore underground HVDC cable routes of approximately 65 to 75 km depending on landfall selection. Works at the existing West Burton substation would also be required to accommodate the connection to the wider transmission system.

7.2 Environmental and Socio-economic Appraisal

7.2.1 An environmental and socio-economic appraisal has been undertaken of two new transmission circuits making landfall on the Lincolnshire coast and connecting to the West Burton Substation in Nottinghamshire.

7.2.2 For the purposes of the appraisal a study area was established in which the terrestrial elements of EGL3 and EGL4 (comprising underground cables and converter stations) could reasonably be expected to be developed. This extended from the Lincolnshire coastline (between south of Cleethorpes and north of Chapel St Leonards) inland to the point of connection at the existing West Burton substation. The appraisal has also considered marine environmental and socio-economic factors in so far as they may be a differentiator between options, for example increased subsea cable route length in the marine environment and/or potentially impacting different or additional marine environmental or socio-economic considerations.

7.2.3 There are a number of statutory ecological designations present within the marine environment which could potentially be impacted subject to route and landfall selection. These include the Southern North Sea SAC, Greater Wash SPA, Holderness Inshore MCZ, Holderness Offshore MCZ and subject to how far south the landfall is located the Inner Dowsing, Race Bank and North Ridge SAC. However, these sites would influence the development of any subsea cable route making landfall on the Lincolnshire coast and therefore are not a significant differentiator between the strategic options being assessed.

7.2.4 The Lincolnshire coastline is also subject to a number of statutory ecological designations including the Humber Estuary SPA, SAC and SSSI, Saltfleetby-Theddlethorpe Dunes & Gibraltar Point SAC, Saltfleetby-Theddlethorpe Dunes SSSI and NNR and Donna Nook NNR located as well as Sea Bank Clay Pits SSSI and Chapel Point to Wolla Bank SSSI. These sites are all potentially avoidable, subject to landfall selection as well as cable installation methods (for example Horizontal Directional Drilling or adherence to seasonal working restrictions) so are not considered to be a significant constraint on this option.

7.2.5 Underground cable routeing towards West Burton is more constrained compared to other strategic options due to the requirement for longer, direct routes crossing the Lincolnshire Wolds AONB. The landscape designation extends north to south across the study area and would require to be crossed by underground cable routes unless significantly longer, less direct routes were developed to avoid it to the north or south. It should also be noted that there is a proposal to extend the AONB's northern boundary potentially limiting opportunities to avoid the AONB to longer, less direct routes to the south of it. While long term impacts on the AONB should be limited as result of the use of underground cables, alternative options which can avoid it would be preferable, including in order to address planning policy requirements.

7.2.6 There are additional statutory ecological and historic environment designations present in the study area including a number of SSSIs and scheduled monuments as well as Registered Parks and Gardens, but impacts on these are considered to be avoidable with careful routeing and/or adoption of appropriate mitigation. Settlements are present throughout the study area, however, their size and distribution means that they can be avoided with careful routeing. There are statutory ecological and historic environment designations in the vicinity of West Burton which would require to be avoided in site and route selection. The existing industrial character of the immediate area around the connection provides some opportunities to sensitively site converter stations close to it. However, there are also proposals for large scale solar development in this area which could affect siting and routeing options.

7.2.7 Overall, on the basis of the information currently available and assuming that appropriate mitigation is undertaken, together with sensitive routing and siting, the majority of environmental and socio-economic factors are not considered to significantly constrain option EGL OPP1. However, the requirement to route across the Lincolnshire Wolds AONB makes potential strategic option EGL OPP1 less preferable in environmental terms.

7.3 Technical Appraisal

7.3.1 Alongside the environmental and socio-economic appraisal of the option a technical appraisal has established that EGL OPP2 would satisfy the NETS SQSS and meet the requirements to resolve system boundaries B6, B7a and B8 as stated in the need case. However, connection to West Burton would require additional works to resolve the B9 system boundary issue.

7.3.2 Technical analysis of this option included consideration of the following:

- This option does not cross the B9 system boundary and therefore would require additional works to resolve Part Two of the need case completely.
- The option will significantly increase the loading on the existing circuits flowing south from West Burton impacting the B9 system boundary.

7.4 Cost Appraisal

7.4.1 As set out in Section 6, we undertook a cost evaluation of the following two technologies for subsea options evaluation.

- 400 kV AC subsea cable
- 525 kV HVDC subsea cable

7.4.2 Option EGL OPP1 requires the following transmission works to satisfy the requirements of the NETS SQSS.

- New Circuit requirements
  a) AC subsea connections circuit options use Med capacity double circuits (two 400 kV AC circuits) with a total capacity of up to 6380 mega volt amperes (MVA) of a distance of 625km; As we only require one AC double circuit cable we only consider this technology over the longest distance as we will pick up both Scottish connection points with the one double circuit AC connection then on to the connection point in England.or
  b) Subsea HVDC connection options use 525 kV 2 GW voltage source links, which would require a converter station at each end, similar in size to a large warehouse. In this case a 4 GW connection would require four converter stations in total, with up to two of the converters located at West Burton substation.
  c) Subsea HVDC cables totalling, EGL 3 – 625km and EGL 4 – 521km with total combined distance 1146 km. The onshore HVDC cables to the connection point are included in this cost and distance.
- NGET Substation Works
  a) 4 new bays at West Burton substation and connections to the new converter stations.

7.4.3 Table 7.1 below sets out the capital costs for option EGL OPP1.

Table 7.1 – Option EGL OPP1: capital cost for each technology option

Item	**Need**	**EGL OPP1 Capital Cost**	
Substation Works	Facilitate Generation and connect new circuits	£120.0m	
New Circuits		**AC Subsea Cable (625km)**	**Subsea HVDC (1146km)**
New Circuit	New Circuit across the B6,B7a and B8 system boundaries	£19,130.2m	£4,609.9m
Total Capital Cost		**£19,250.2m**	**£4,729.9m**

7.4.4 **Table 7.2** below sets out the lifetime cost for the new circuit options, the lifetime costs are different for each circuit technology and are included as a differentiator between technologies. These costs are calculated using the methodology described in “Strategic options technical appendix 2020/2021 price base” Appendix D.

Table 7.2 – Option EGL OPP1: lifetime cost for each technology option

Subsea Based Option	AC Subsea Cable	Subsea HVDC
Capital Cost of New Circuits	£19,130.2m	£4,609.9m
NPV of Cost of Losses over 40 years	£1,253.5m	£314.2m
NPV of Operation & Maintenance Costs over 40 Years	£112.9m	£117.5m
Lifetime Cost of New Circuits	**£20,497m**	**£5,042m**

7.5 Summary

7.5.1 Potential strategic option EGL OPP1 comprises new transmission circuits from Peterhead, Aberdeenshire (EGL3) and Westfield, Fife (EGL4) connecting to the existing West Burton substation in Nottinghamshire. We note from the outputs of our appraisal that EGL OPP1 would provide additional boundary capability on B6, B7a and B8 system boundaries, however, it would not provide additional capability on the B9 system boundary. It should also be noted this option would require further works to resolve B9 system boundary issues. While the environmental and socio-economic appraisal has not identified any factors which prevent EGL OPP1, the requirement to route across the Lincolnshire Wolds AONB makes it less preferable in environmental and planning policy compliance terms, compared to other options which avoid the AONB.

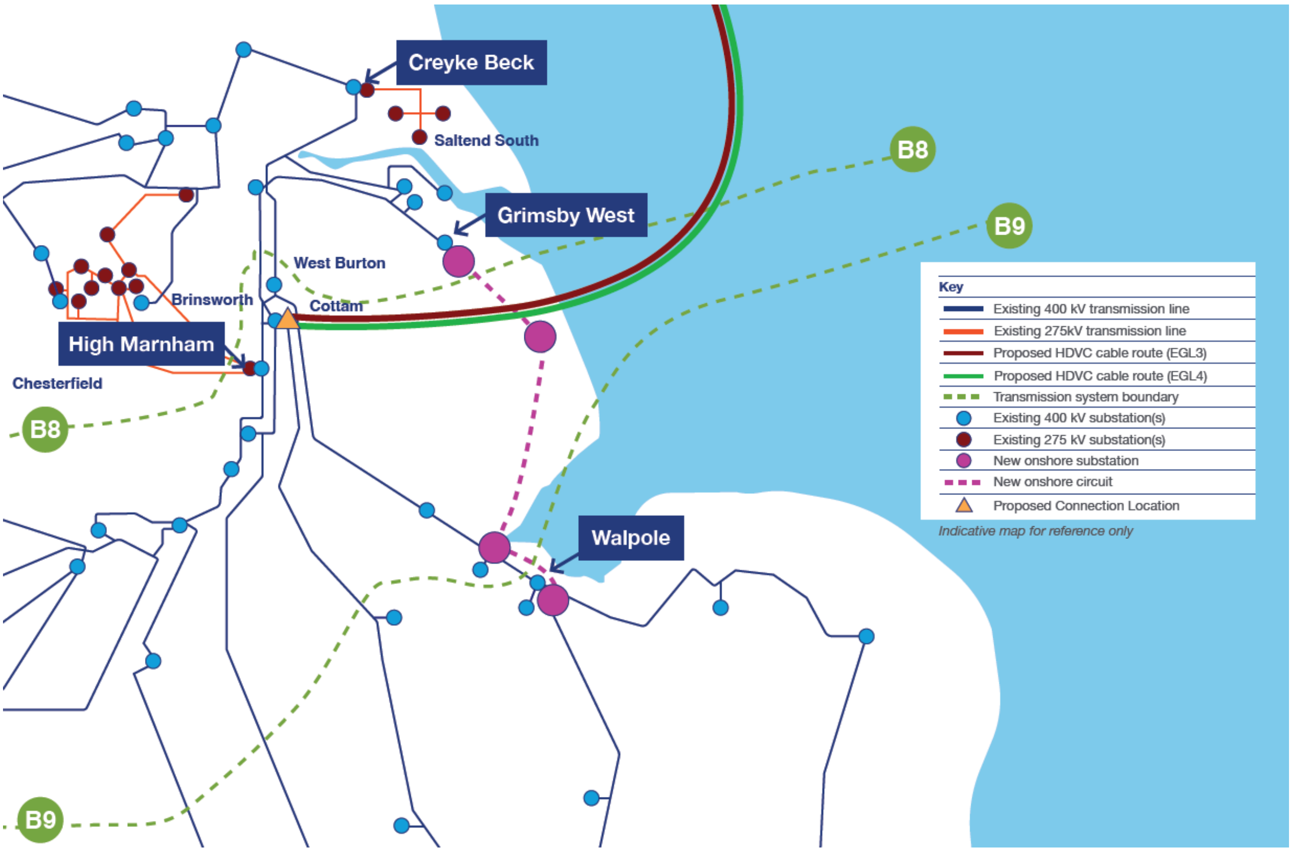
8. Appraisal of potential strategic option EGL OPP2 Cottam substation

8.1 Overview of EGL OPP2

8.1.1 Option EGL OPP3 involves the development of new transmission circuits from Peterhead, Aberdeenshire (EGL3) and Westfield, Fife (EGL4) connecting to the existing Cottam substation in Nottinghamshire. The majority of the new circuits would be routed within the North Sea making landfall on the Lincolnshire coastline between the Humber and the Wash. The marine element of EGL OPP2 is common to other options with the main difference being where the landfall is located (i.e. how far south the submarine cables are routed).

8.1.2 Figure 8.1 below shows a diagram of the location of the EGL OPP2 Cottam potential strategic option considered within this report.

Figure 8.1 – EGL OPP2 Cottam potential strategic option



8.1.3 The circuit distances for this connection are set out below. These are based on subsea cable route distances from a preliminary cable routeing study and the longest straight-line distance from a landfall on the Lincolnshire coastline to the existing Cottam substation.

- EGL 3 655km
- EGL 4 551km
- Total combined distance 1206km

8.1.4 This option is formed of two HVDC links which would require two pairs of two HVDC cables (i.e. 4 cables in total) as well as converter stations at either end of the links (one in Peterhead, one in Westfield and two converter stations at Cottam). This option would require two converter stations with an approximate footprint of 6 ha each (an indicative diagram is provided in Appendix C), as well as onshore underground HVDC cable routes of approximately 69 to 77 km depending on landfall selection. Works at the existing Cottam substation would also be required to accommodate the connection to the wider transmission system.

8.2 Environmental and Socio-economic Appraisal

8.2.1 An environmental and socio-economic appraisal has been undertaken of two new transmission circuits making landfall on the Lincolnshire coast and connecting to the Cottam Substation in Nottinghamshire.

8.2.2 For the purposes of the appraisal a study area was established in which the terrestrial elements of EGL3 and 4 (comprising underground cables and converter stations) could reasonably be expected to be developed. This extended from the Lincolnshire coastline (between south of Cleethorpes and north of Chapel St Leonards) inland to the point of connection at the existing Cottam substation. The appraisal has also considered marine environmental and socio-economic factors in so far as they may be a differentiator between options, for example increased subsea cable route length in the marine environment and/or potentially impacting different or additional marine environmental or socio-economic considerations.

8.2.3 There are a number of statutory ecological designations present within the marine environment which could potentially be impacted subject to subsea cable routeing and landfall siting on the Lincolnshire coast. These include the Southern North Sea SAC, Greater Wash SPA, Holderness Inshore MCZ Holderness Offshore MCZ and subject to how far south the landfall is located potentially also the Inner Dowsing, Race Bank and North Ridge SAC. However, these sites are common to any subsea cable route making landfall on the Lincolnshire coast and therefore are not a significant differentiator between the strategic options being assessed.

8.2.4 The Lincolnshire coastline is also subject to a number of statutory ecological designations. From north to south this includes the Humber Estuary SPA, SAC and SSSI, Saltfleetby-Theddlethorpe Dunes & Gibraltar Point SAC, Saltfleetby-Theddlethorpe Dunes SSSI and NNR and Donna Nook NNR as well as Sea Bank Clay Pits SSSI and Chapel Point to Wolla Bank SSSI. These sites are potentially avoidable through landfall selection. Where landfalls are located within coastal ecological designations, impacts may be avoided through a choice of cable installation methods (for example trenchless methods such as Horizontal Directional Drilling [HDD]) or adherence to seasonal working restrictions). As result coastal ecological designations are not considered to be a significant constraint on this option.

8.2.5 Underground cable routeing towards Cottam is more constrained compared to some other strategic options due to the requirement for longer, direct routes crossing the Lincolnshire Wolds AONB. The landscape designation extends north to south across the study area and would require to be crossed by underground cable routes unless significantly longer, less direct routes were developed to avoid it to the north or south. It should also be noted that there is a proposal to extend the AONB's northern boundary potentially limiting opportunities to avoid the AONB to longer, less direct routes to the south of it. While long term impacts on the AONB should be mitigated as a result of the use of underground cables as well as careful routeing and reinstatement, alternative options which can avoid direct impacts on it would be preferable, including in order to address planning policy requirements.

8.2.6 There are additional statutory ecological and historic environment designations present in the study area including a number of SSSIs and scheduled monuments as well as Registered Parks and Gardens, but impacts on these are considered to be avoidable with careful routeing and/or adoption of appropriate mitigation. Settlements are present throughout the study area, however, their size and distribution means that they can be avoided with careful routeing. With the exception of a scheduled monument, there are no statutory designations in the immediate vicinity of Cottam. This combined with the existing industrial character of the immediate area provides some opportunities to sensitively site converter stations close to the connection point. However, there are also proposals for large scale solar development in this area which could affect the availability of land for siting and routeing.

8.2.7 Overall, on the basis of the information currently available and assuming that appropriate mitigation is undertaken, together with sensitive routing and siting, the majority of environmental and socio-economic factors are not considered to significantly constrain option EGL OPP2. However, the requirement to route across the Lincolnshire Wolds AONB makes Option EGL OPP2 less preferable in environmental terms.

8.3 Technical Appraisal

8.3.1 Alongside the environmental and socio-economic appraisal of the option a technical appraisal has established that EGL OPP2 would satisfy the NETS SQSS and meet the requirements to resolve system boundaries B6, B7a and B8 as stated in the need case. However, connection to Cottam would require additional works to resolve the B9 system boundary issue.

8.3.2 Technical analysis of this option included consideration of the following:

- This option does not cross the B9 system boundary and therefore would require additional works to resolve the need case completely.
- The option will significantly increase the loading on the existing circuits flowing south from Cottam impacting the B9 system boundary.

8.4 Cost Appraisal

8.4.1 As set out in Section 6, we undertook a cost evaluation of the following two technologies for subsea options evaluation:

- 400 kV AC subsea cable
- 525 kV HVDC subsea cable

8.4.2 Option EGL OPP2 requires the following transmission works to satisfy the requirements of the NETS SQSS.

- New Circuit requirements
  a) AC subsea connections circuit options use Med capacity double circuits (two 400 kV AC circuits) with a total capacity of up to 6380 mega volt amperes (MVA) of a distance of 655km; As we only require one AC double circuit cable we only consider this technology over the longest distance as we will pick up both Scottish connection points with the one double circuit AC connection then on to the connection point in England. or
  b) Subsea HVDC connection options use 525 kV 2 GW voltage source links, which would require a converter station at each end, similar in size to a large warehouse. In this case a 4 GW connection would require four converter stations in total, with up to two of the new converters located at Cottam substation.
  c) Subsea HVDC cables totalling, EGL 3 - 655km and EGL 4 - 551km with total combined distance 1206km. the onshore HVDC cables to the connection point are included in this cost and distance.
- NGET Substation Works
  – 4 new bays at Cottam substation and connections to the new converter stations.

8.4.3 Table **8.1** below sets out the capital costs for potential strategic option EGL OPP2.

Table 8.1 – Option EGL OPP2: capital cost for each technology option

Item	Need	EGL OPP2 Capital Costs	
Substation Works	Facilitate Generation and connect new circuits	£120.0m	
New Circuits		**AC Subsea Cable (655km)**	**Subsea HVDC (1206km)**
New Circuit	New Circuit across the B6,B7a and B8 system boundaries	£20,050.4m	£4,795.3m
Total Capital Cost		**£20,170.4m**	**£4,915.3m**

8.4.4 Table 8.2 below sets out the lifetime cost for the new circuit options, the lifetime costs are different for each circuit technology and are included as a differentiator between technologies. These costs are calculated using the methodology described in “Strategic options technical appendix 2020/2021 price base” Appendix D.

Table 8.2 – Option EGL OPP2: lifetime cost for each technology option

Subsea Based Option	EGL OPP2 AC Subsea Cable	EGL OPP2 Subsea HVDC
Capital Cost of New Circuits	£20,050.4m	£4,795.3m
NPV of Cost of Losses over 40 years	£1,314.4m	£314.2m
NPV of Operation & Maintenance Costs over 40 Years	£118.4m	£117.7m
Lifetime Cost of New Circuits	**£21,483m**	**£5,227m**

8.5 Summary

8.5.1 Potential strategic option EGL OPP2 comprises new transmission circuits from Peterhead, Aberdeenshire (EGL3) and Westfield, Fife (EGL4) connecting to the existing Cottam substation in Nottinghamshire. We note from the outputs of our appraisal that EGL OPP2 would provide additional boundary capability on B6, B7a and B8 system boundaries, however, it would not provide capability on the B9 system boundary. It should also be noted this option would require further works to resolve B9 system boundary issues. While the environmental and socio-economic appraisal has not identified any factors which prevent EGL OPP2, the requirement to route across the Lincolnshire Wolds AONB makes it less preferable in environmental and planning policy compliance terms compared to other options which avoid the AONB.

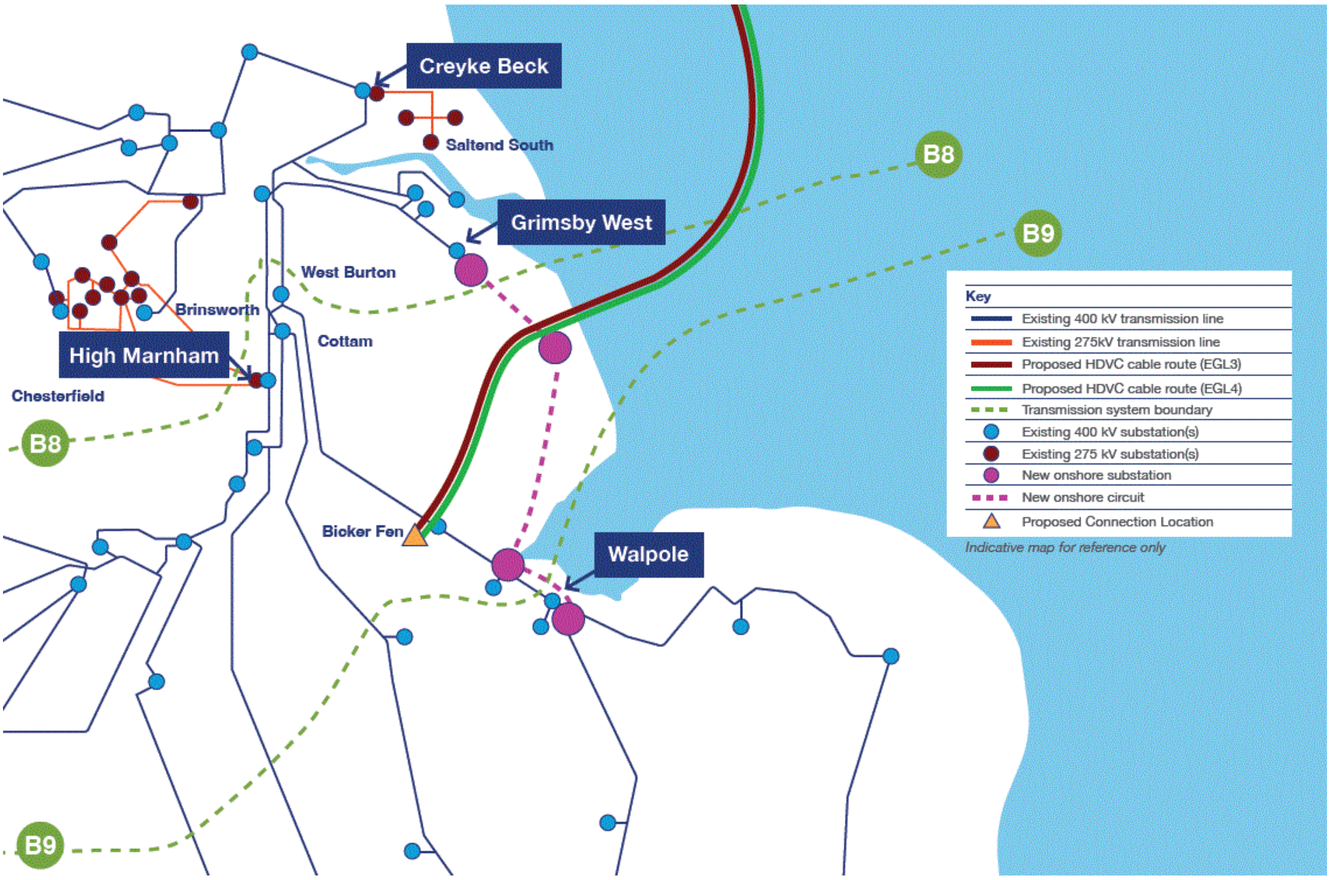
9. Appraisal of potential strategic option EGL OPP3 Bicker Fen substation

9.1 Overview of EGL OPP3

9.1.1 Option EGL OPP3 involves the development of new transmission circuits from Peterhead, Aberdeenshire (EGL3) and Westfield, Fife (EGL4) connecting to the existing Bicker Fen substation. The majority of the new circuits would be routed within the North Sea making landfall on the Lincolnshire coastline between the Humber and the Wash. The marine element of EGL OPP3 is common to all strategic options with the main difference being where the landfall is located (i.e. how far south the submarine cables are routed).

9.1.2 Figure 9.1 below shows a diagram of the location of the EGL OPP3 Bicker Fen potential strategic option considered within this report.

Figure 9.1 – EGL OPP3 Bicker Fen potential strategic option



9.1.3 The circuit distances for this connection are set out below. These are based on subsea cable route distances from a preliminary cable routeing study and the longest straight-line distance from a landfall on the Lincolnshire coastline to the existing Bicker Fen substation.

- EGL 3 620km
- EGL 4 516km
- Total combined distance 1136km

9.1.4 This option is formed of two HVDC links which would require two pairs of two HVDC cables (i.e. 4 cables in total) as well as converter stations at either end of the links (one in Peterhead, one in Westfield and two converter stations at Bicker Fen). This option would require two converter stations with an approximate footprint of 6 ha each (an indicative diagram is provided in Appendix C) as well as onshore underground HVDC cable routes of approximately 42 to 65 km depending on landfall selection. Works at the existing Bicker Fen substation would also be required to accommodate the connection to the wider transmission system.

9.2 Environmental and Socio-economic Appraisal

9.2.1 An environmental and socio-economic appraisal has been undertaken of two new transmission circuits making landfall on the Lincolnshire coast and connecting to the existing Bicker Fen Substation in Boston Borough.

9.2.2 For the purposes of the appraisal a study area was established in which the terrestrial elements of EGL3 and EGL4 (comprising underground cables and converter stations) could reasonably be expected to be developed. This extended from the Lincolnshire coastline (between south of Cleethorpes and north of Chapel St Leonards) inland to the point of connection at Bicker Fen substation. The appraisal has also considered marine environmental and socio-economic factors in so far as they may be a differentiator between options, for example increased subsea cable route length in the marine environment and/or potentially impacting different or additional marine environmental or socio-economic considerations.

9.2.3 There are a number of statutory ecological designations present within the marine environment which could potentially be impacted subject to subsea cable routeing and landfall siting on the Lincolnshire coast. These include the Southern North Sea SAC, Greater Wash SPA, Holderness Inshore MCZ, Holderness Offshore MCZ and subject to how far south the landfall is located the Inner Dowsing, Race Bank and North Ridge SAC. However, these sites are common to any subsea cable route making landfall on the Lincolnshire coast and therefore are not a significant differentiator between the strategic options being assessed.

9.2.4 The Lincolnshire coastline is also subject to a number of statutory ecological designations. From north to south this includes the Humber Estuary SPA, SAC and SSSI, Saltfleetby-Theddlethorpe Dunes & Gibraltar Point SAC, Saltfleetby-Theddlethorpe Dunes SSSI and NNR and Donna Nook NNR located as well as Sea Bank Clay Pits SSSI and Chapel Point to Wolla Bank SSSI. These sites are potentially avoidable through landfall selection. Where landfalls are located within coastal ecological designations, impacts may be avoided through a choice of cable installation methods (for example trenchless methods such as Horizontal Directional Drilling [HDD]) or adherence to seasonal working restrictions). As result coastal ecological designations are not considered to be a significant constraint on this option.

9.2.5 While underground cable routes to Bicker Fen would be longer than other routes, the study area is not considered to be highly constrained in terms environmental designations. Part of the Lincolnshire Wolds AONB extends into the north of the study area while the Wash SPA, SAC and SSSI lie to the south. However, these sites can be avoided with careful routeing. Subject to detailed routeing there may be some potential for disturbance and/or displacement impacts where qualifying bird species of the Wash SPA utilise adjacent agricultural land, however, this should be temporary for the duration of cable installation only. There are SSSIs as well as scheduled monuments present within the area between the Lincolnshire coastline and Bicker Fen but these designations occupy small areas and can be avoided with careful routeing.

9.2.6 Small and moderately sized settlements are present throughout the study area often coalescing along main transport routes including A16 and A52. Much of the land within the study area comprises agricultural land with an Agricultural Land Capability classification of grade 1 or 2. This does not prevent cable routeing through these areas but highlights the need for effective soil management and reinstatement for underground cable routes to converter stations in the Bicker Fen area.

9.2.7 There are no statutory landscape, ecological and historic environment designations in the vicinity of Bicker Fen which would influence site selection. Key factors which could influence site selection relate to other energy projects close to and/or connecting to Bicker Fen including Triton Knoll Offshore Wind Farm, Viking Link Interconnector and solar developments. Overall, on the basis of the information currently available and assuming that appropriate mitigation is undertaken, together with sensitive routing and siting, environmental and socio-economic factors are not considered to significantly constrain option EGL OPP3.

9.3 Technical Appraisal

9.3.1 Alongside the environmental and socio-economic appraisal of the option a technical appraisal has established that EGL OPP3 would satisfy the NETS SQSS and meet the requirements to resolve system boundaries B6, B7a and B8 as stated in the need case. However, connection to Bicker Fen would require additional works to resolve the B9 system boundary issue.

9.3.2 Technical analysis of this option included consideration of the following:

- This option does not cross the B9 system boundary and therefore would require additional works to resolve the need case completely.
- The option will significantly increase the loading on the existing circuits flowing south from Bicker Fen impacting the B9 system boundary.

9.4 Cost Appraisal

9.4.1 As set out in Section 6, we undertook a cost evaluation of the following two technologies for subsea options evaluation.

- 400 kV AC subsea cable
- 525 kV HVDC subsea cable

9.4.2 Option EGL OPP3 requires the following transmission works to satisfy the requirements of the NETS SQSS.

- New Circuit requirements
    a) AC subsea connections circuit options use Med capacity double circuits (two 400 kV AC circuits) with a total capacity of up to 6380 mega volt amperes (MVA) of a distance of 620km. As we only require one AC double circuit cable we only consider this technology over the longest distance as we will pick up both Scottish connection points with the one double circuit AC connection then on to the connection point in England;.or
    b) Subsea HVDC connection options use 525 kV 2 GW voltage source links, which would require a converter station at each end, similar in size to a large warehouse. In this case a 4 GW connection would require four new converter stations in total, with up to two of the converters located at the Bicker Fen substation
    c) Subsea HVDC cables totalling, EGL 3 – 620km and EGL 4 – 516km with total combined distance 1136km. The onshore HVDC cables to the connection point are included in this cost and distance.
- NGET Substation Works
    a) 4 new bays Bicker Fen Substation and connections to the new converter stations.

9.4.3 **Table 9.1** below sets out the capital costs for potential strategic option EGL OPP3

Table 9.1 – Option EGL OPP3: capital cost for each technology option

Item	Need	EGL OPP3 Capital Cost	
Substation Works	Facilitate Generation and connect new circuits	£120.0m	
New Circuits		**AC Subsea Cable (620km)**	**Subsea HVDC (1136km)**
New Circuit	New Circuit across the B6, B7a and B8 system boundaries	£18,971.2m	£4,579.0m
Total Capital Cost		**£19,091.2m**	**£4,699.0m**

9.4.4 **Table 9.2** below sets out the lifetime cost for the new circuit options, the lifetime costs are different for each circuit technology and are included as a differentiator between technologies. These costs are calculated using the methodology described in "Strategic options technical appendix 2020/2021 price base" Appendix D.

Table 9.2 – Option EGL OPP3: lifetime cost for each technology option

Subsea Based Option	EGL OPP3 AC Subsea Cable	EGL OPP3 Subsea HVDC
Capital Cost of New Circuits	£18,971.2m	£4,579.0m
NPV of Cost of Losses over 40 years	£1,238.8m	£314.2m
NPV of Operation & Maintenance Costs over 40 Years	£112.0m	£117.5m
Lifetime Cost of New Circuits	**£20,322m**	**£5,011m**

9.5 Summary

9.5.1 EGL OPP3 comprises new transmission circuits from Peterhead, Aberdeenshire (EGL3) and Westfield, Fife (EGL4) connecting to the existing Bicker Fen Substation in Boston Borough. We note from the outputs of our appraisal that EGL OPP3 would provide additional boundary capability on B6, B7a and B8 system boundaries, however, it would not provide capability on the B9 system boundary. It should also be noted this option would require further works to resolve B9 system boundary issues. Subject to sensitive routeing and siting, the environmental and socio-economic appraisal has not identified any factors which would significantly constrain or prevent EGL OPP3.

10. Appraisal of potential strategic option EGL OPP4 New Weston Marsh substation

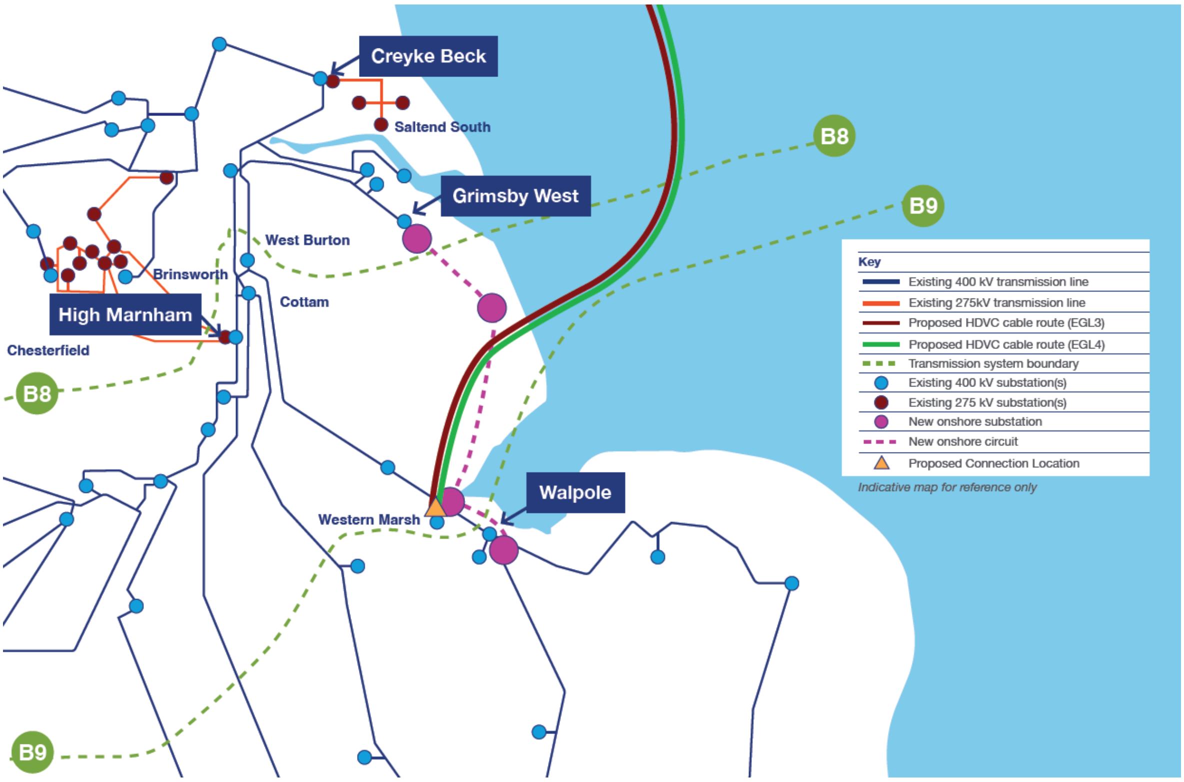
10.1 Overview of EGL OPP4

10.1.1 Option EGL OPP4 involves the development of new transmission circuits from Peterhead, Aberdeenshire (EGL3) and Westfield, Fife (EGL4) connecting to a new Weston Marsh Substation. The majority of the new circuits would be routed within the North Sea making landfall on the Lincolnshire coastline between the Humber and the Wash. The marine element of EGL OPP4 is common to all strategic options with the main difference being where the landfall is located (i.e. how far south the submarine cables are routed).

10.1.2 The new Weston Marsh substation is proposed as part of the Grimsby to Walpole reinforcement and therefore will subject to an application for development consent in the future. For the purposes of the appraisal of EGL OPP4, consideration has been given to the additional costs or impacts of extending Weston Marsh to connect EGL OPP4.

10.1.3 Figure 10.1 below shows a diagram of the location of the EGL OPP4 New Weston Marsh potential strategic option considered within this report.

10.1.4 Figure 10.1 – EGL OPP4 New Weston Marsh potential strategic option



10.1.5 The circuit distances for this connection are set out below. These are based on subsea cable route distances from a preliminary cable routeing study and the longest straight-line distance from a landfall on the Lincolnshire coastline to the new Weston Marsh substation.

- EGL3 627km
- EGL4 523km
- Total combined distance 1150km

10.1.6 This option is formed of two HVDC links which would require two pairs of two HVDC cables (i.e. 4 cables in total) as well as converter stations at either end of the links (one in Peterhead, one in Westfield and two converter stations at Weston Marsh).

10.1.7 This option would require two converter stations with an approximate footprint of 6 ha each (an indicative diagram is provided in Appendix C) as well as onshore underground HVDC cable routes of approximately 54 to 72 km depending on landfall selection. A new Weston Marsh substation (currently being considered as part of the NGET's Grimsby to Walpole project) would also be required to accommodate EGL OPP4.

10.2 Environmental and Socio-economic Appraisal

10.2.1 An environmental and socio-economic appraisal has been undertaken of two new transmission circuits making landfall on the Lincolnshire coast and connecting to the new Weston Marsh substation.

10.2.2 For the purposes of the appraisal a study area was established in which the terrestrial elements of EGL3 and EGL4 (comprising underground cables and converter stations) could reasonably be expected to be developed. This extended from the Lincolnshire coastline (between south of Cleethorpes and north of Chapel St Leonards) inland to the point of connection at a new Weston Marsh substation. The appraisal has also considered marine environmental and socio-economic factors in so far as they may be a differentiator between options, for example increased subsea cable route length in the marine environment and/or potentially impacting different or additional marine environmental or socio-economic considerations.

10.2.3 There are a number of statutory ecological designations present within the marine environment which could potentially be impacted subject to subsea cable routeing and landfall siting on the Lincolnshire coast. These include the Southern North Sea SAC, Greater Wash SPA, Holderness Inshore MCZ, Holderness Offshore MCZ and subject to how far south the landfall is located the Inner Dowsing, Race Bank and North Ridge SAC. However, these sites are common to any subsea cable route making landfall on the Lincolnshire coast and therefore are not a significant differentiator between the strategic options being assessed.

10.2.4 The Lincolnshire coastline is also subject to a number of statutory ecological designations. From north to south this includes the Humber Estuary SPA, SAC and SSSI, Saltfleetby-Theddlethorpe Dunes & Gibraltar Point SAC, Saltfleetby-Theddlethorpe Dunes SSSI and NNR and Donna Nook NNR as well as Sea Bank Clay Pits SSSI and Chapel Point to Wolla Bank SSSI. These sites are potentially avoidable through landfall selection. Where landfalls are located within coastal ecological designations, impacts may be avoided through a choice of cable installation methods (for example trenchless methods such as Horizontal Directional Drilling [HDD]) or adherence to seasonal working restrictions). As a result, coastal ecological designations are not considered to be a significant constraint on this option.

10.2.5 Environmental and socio-economic constraints influencing underground cable routes to Weston Marsh are similar to those for Bicker Fen and Walpole (via Lincolnshire); the study area is not considered to be highly constrained in terms environmental designations. Part of the Lincolnshire Wolds AONB extends into the north of the study area while the Wash SPA, SAC and SSSI lie to the south, however, these sites can be avoided with careful routeing. Subject to detailed routeing there may be some potential for disturbance and/or displacement impacts where qualifying bird species of the Wash SPA utilise adjacent agricultural land, however, this should be temporary for the duration of cable installation only. There are a small number of SSSIs and scheduled monuments present within the area between the Lincolnshire coastline and Weston Marsh but these designations occupy small areas and can be avoided with careful routeing therefore are not considered to materially influence this option.

10.2.6 Small and moderately sized settlements are present throughout the study area often coalescing along main transport routes including A16 and A52. Boston is a key constraint and will influence the underground cable routeing and cable distances e.g. either north and west or south and east of the settlement.

10.2.7 The majority of land within the study area comprises agricultural land with an Agricultural Land Capability classification of grade 1 or 2. This does not prevent cable routeing through these areas but highlights the need for effective soil management and reinstatement for underground cable routes to converter stations in the vicinity of Weston Marsh.

10.2.8 There is one scheduled monument in the vicinity of Weston Marsh the setting of which could be impacted by the siting of converter stations. Converter stations in the Weston Marsh area have the potential to result in long term landscape and visual effects due to the introduction of new infrastructure in a landscape which currently has little major development. This includes the potential for cumulative effects in combination with the new Weston Marsh substation (proposed as part of the Grimsby to Walpole reinforcement), however, there may be some opportunities to mitigate this through site selection and design.

10.2.9 Overall, on the basis of the information currently available and assuming that appropriate mitigation is undertaken, together with sensitive routing and siting, environmental and socio-economic factors are not considered to significantly constrain option EGL OPP4.

10.3 Technical Appraisal

10.3.1 Alongside the environmental and socio-economic appraisal of the option a technical appraisal has established that EGL OPP4 would satisfy the NETS SQSS and meet the requirements to resolve system boundaries B6, B7a and B8 as stated in the need case. However, connection to the new Weston Marsh substation would require additional works to resolve the B9 system boundary issue.

10.3.2 Technical analysis of this option included consideration of the following:

- This option does not cross the B9 system boundary and therefore would require additional works to resolve Part Two of the need case completely.
- The option will significantly increase the loading on the existing circuits flowing south from Weston Marsh impacting the B9 system boundary.

10.4 Cost Appraisal

10.4.1 As set out in Section 6, we undertook a cost evaluation of the following two technologies for subsea options evaluation.

- 400 kV AC subsea cable
- 525 kV HVDC subsea cable

10.4.2 Option EGL OPP4 requires the following transmission works to satisfy the requirements of the NETS SQSS.

- New Circuit requirements
  a) AC subsea connections circuit options use Med capacity double circuits (two 400 kV AC circuits) with a total capacity of up to 6380 mega volt amperes (MVA) of a distance of 627km. As we only require one AC double circuit cable, we only consider this technology over the longest distance as we will pick up both Scottish connection points with the one double circuit AC connection then on to the connection point in England; or
  b) Subsea HVDC connection options use 525 kV 2 GW voltage source links, which would require a converter station at each end, similar in size to a large warehouse. In this case a 4 GW connection would require four converter stations in total, with up to two of the converters located at the new Weston Marsh substation
  c) Subsea HVDC cables totalling, EGL 3 – 627km and EGL 4 – 523km with total combined distance 1150km. The onshore HVDC cables to the connection point are included in this cost and distance.

- NGET Substation Works
  a) 4 new bays at new Weston Marsh substation and connections to the new converter stations.

10.4.3 Table 10.1 below sets out the capital costs for potential strategic option EGL OPP4.

Table 10.1 – Option EGL OPP4: capital cost for each technology option

Item	Need	EGL OPP4 Capital Cost	
Substation Works	Facilitate Generation and connect new circuits	£120.0m	
New Circuits		**AC Subsea Cable (627km)**	**Subsea HVDC (1150km)**
New Circuit	New Circuit across the B6, B7a and B8 system boundaries	£19,186.8m	£4,622.3m
Total Capital Cost		**£19,306.8m**	**£4,742.3m**

10.4.4 Table 10.2 below sets out the lifetime cost for the new circuit options, the lifetime costs are different for each circuit technology and are included as a differentiator between technologies. These costs are calculated using the methodology described in "Strategic options technical appendix 2020/2021 price base" Appendix D.

Table 10.2 – Option EGL OPP4: lifetime cost for each technology option

Subsea Based Option	EGL OPP4 AC Subsea Cable	EGL OPP4 Subsea HVDC
Capital Cost of New Circuits	£19,186.8m	£4,622.3m
NPV of Cost of Losses over 40 years	£1,255.7m	£314.2m
NPV of Operation & Maintenance Costs over 40 Years	£113.1m	£117.5m
Lifetime Cost of New Circuits	**£20,556m**	**£5,054m**

10.5 Summary

10.5.1 EGL OPP4 comprises new transmission circuits from Peterhead, Aberdeenshire (EGL3) and Westfield, Fife (EGL4) connecting to a new Weston Marsh substation. We note from the outputs of our appraisal that EGL OPP4 would provide additional boundary capability on B6, B7a and B8 system boundaries, however, it would not provide capability on the B9 system boundary. It should also be noted this option would require further works to resolve B9 system boundary issues. Subject to sensitive routeing and siting, the environmental and socio-economic appraisal has not identified any factors which would significantly constrain or prevent EGL OPP4.

11. Appraisal of potential strategic option EGL OPP5 New Lincolnshire Connection Substation(s)

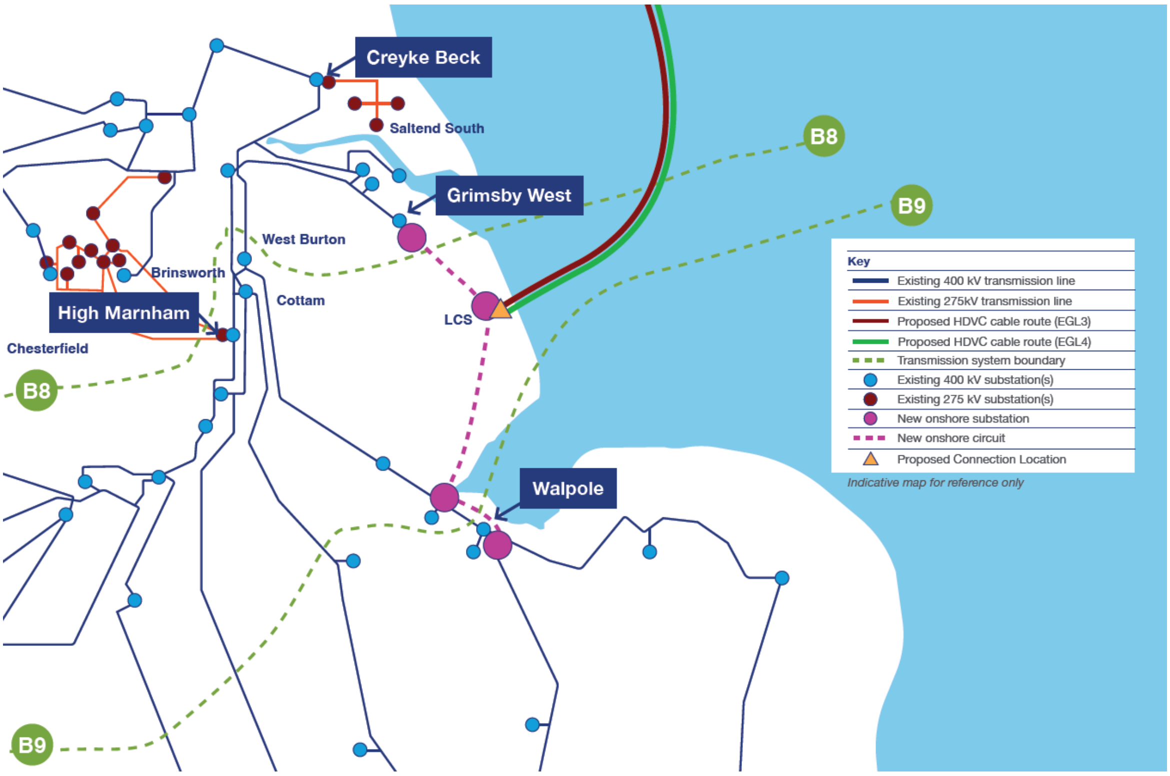
11.1 Overview of OPP5

11.1.1 Option EGL OPP5 involves the development of new transmission circuits from Peterhead, Aberdeenshire (EGL3) and Westfield, Fife (EGL4) connecting to a new Lincolnshire Connections substation in East Lindsey. The majority of the new circuits would be routed within the North Sea making landfall on the Lincolnshire coastline between the Humber and the Wash. The marine element of EGL OPP5 is common to all strategic options with the main difference being where the landfall is located (i.e. how far south the submarine cables are routed).

11.1.2 The Lincolnshire Connection substation(s) is proposed as part of the Grimsby to Walpole reinforcement and therefore will subject to an application for development consent in the future. For the purposes of the appraisal of EGL OPP5, consideration has been given to the additional costs or impacts of extending the Lincolnshire Connection substation(s) to connect EGL OPP5.

11.1.3 Figure 11.1 below shows a diagram of the location of the EGL OPP5 New Lincolnshire Connection substation(s) potential strategic option considered within this report.

Figure 11.1 – EGL OPP5 New Lincolnshire Connection Substation(s) potential strategic option



11.1.0 The circuit distances for this connection are set out below. These are based on subsea cable route distances from a preliminary cable routeing study and the longest straight-line distance from a landfall on the Lincolnshire coastline to the new Lincolnshire Connection substation(s).

- EGL 3 565km
- EGL 4 461km
- Total combined distance 1026km

11.1.1 This option is formed of two HVDC links which would require two pairs of two HVDC cables (i.e. 4 cables in total) as well as converter stations at either end of the links (one in Peterhead, one in Westfield and two converter stations at Lincolnshire Connection substation(s)).

11.1.2 This option would require two converter stations with an approximate footprint of 6 ha each (an indicative diagram is provided in Appendix C) as well as onshore underground HVDC cable routes of approximately 6 to 22 km depending on landfall selection. A new substation at Lincolnshire Connection Substation(s) would also be required to accommodate the connection to the wider transmission system. The new Lincolnshire Connection Substation(s) is currently being considered as a requirement for new generation connection projects and would need new overhead lines to connect it to the transmission system.

11.2 Environmental and Socio-economic Appraisal

11.2.1 An environmental and socio-economic appraisal has been undertaken of two new transmission circuits making landfall on the Lincolnshire coast and connecting to the new Lincolnshire Connection Substation(s) in East Lindsey.

11.2.2 For the purposes of the appraisal a study area was established in which the terrestrial elements of EGL3 and EGL4 (comprising underground cables and converter stations) could reasonably be expected to be developed. This extended from the Lincolnshire coastline (between south of Cleethorpes and north of Chapel St Leonards) inland to the point of connection at new West Burton substation. The appraisal has also considered marine environmental and socio-economic factors in so far as they may be a differentiator between options, for example increased subsea cable route length in the marine environment and/or potentially impacting different or additional marine environmental or socio-economic considerations.

11.2.3 There are a number of statutory ecological designations present within the marine environment which could potentially be impacted subject to subsea cable routeing and landfall siting on the Lincolnshire coast. These include the Southern North Sea SAC, Greater Wash SPA, Holderness Inshore MCZ, Holderness Offshore MCZ and subject to how far south the landfall is located the Inner Dowsing, Race Bank and North Ridge SAC. However, these sites are common to any subsea cable route making landfall on the Lincolnshire coast and therefore are not a significant differentiator between the strategic options being assessed.

11.2.4 The Lincolnshire coastline is also subject to a number of statutory ecological designations. From north to south this includes the Humber Estuary SPA, SAC and SSSI, Saltfleetby-Theddlethorpe Dunes & Gibraltar Point SAC, Saltfleetby-Theddlethorpe Dunes SSSI and NNR and Donna Nook NNR located as well as Sea Bank Clay Pits SSSI and Chapel Point to Wolla Bank SSSI. These sites are potentially avoidable through landfall selection. Where landfalls are located within coastal ecological designations, impacts may be avoided through a choice of cable installation methods (for example trenchless methods such as Horizontal Directional Drilling [HDD]) or adherence to seasonal working restrictions). As a result, coastal ecological designations are not considered to be a significant constraint on this option.

11.2.5 Underground cable routeing towards the Lincolnshire Connection substation(s) is less constrained compared to other strategic options due its proximity to the coast and opportunities for shorter, more direct routes. There are fewer statutory ecological or historic environment designations in the area, however those which are present can be avoided with careful route and site selection.

11.2.6 Subject to site selection, the siting of converter stations in the rural/coastal area increases the potential for long-term effects on the setting of scheduled monuments including Markby Priory as well as the potential for long-term effects on views from within the Lincolnshire Wolds AONB. There is the potential to result in long term landscape and visual effects due to the introduction of new infrastructure in a landscape which currently has little major development. This includes the potential for cumulative effects in combination the Lincolnshire Connection substation proposed as part of the Grimsby to Walpole reinforcement. However, there may be opportunities to mitigate this through site selection and design.

11.2.7 Overall, on the basis of the information currently available and assuming that appropriate mitigation is undertaken, together with sensitive routing and siting, environmental and socio-economic factors are not considered to significantly constrain option EGL OPP5. Compared to other options the proximity to the coast provides opportunities for shorter, direct underground cable routes.

11.3 Technical Appraisal

11.3.1 However, connection to the Lincolnshire Connection substation(s) would require additional works to resolve the B9 system boundary issue.

11.3.2 Technical analysis of this option included consideration of the following:

- This option does not cross the B9 system boundary and therefore would require additional works to resolve Part Two of the need case completely.
- The option will significantly increase the loading on the existing circuits flowing south from new Lincolnshire Connection substation(s) impacting the B9 system boundary.

11.4 Cost Appraisal

11.4.1 As set out in Section 6, we undertook a cost evaluation of the following two technologies for subsea options evaluation.

- 400 kV AC subsea cable
- 525 kV HVDC subsea cable

11.4.2 Option EGL OPP5 requires the following transmission works to satisfy the requirements of the NETS SQSS.

- New Circuit requirements

a) AC subsea connections circuit options use Med capacity double circuits (two 400 kV AC circuits) with a total capacity of up to 6380 mega volt amperes (MVA) of a distance of 565km, As we only require one AC double circuit cable we only consider this technology over the longest distance as we will pick up both Scottish connection points with the one double circuit AC connection then on to the connection point in England.; or

b) Subsea HVDC connection options use 525 kV 2 GW voltage source links, which would require a new converter station at each end of each circuit, similar in size to a large warehouse. In this case a 4 GW connection would require four converter stations in total, with up to two of the converters located at the new Lincolnshire Connection substation(s)

c) Subsea HVDC cables totalling, EGL 3 - 565km and EGL 4 - 461km with total combined distance 1026km. The onshore HVDC cables to the connection point are included in this cost and distance.

- NGET Substation Works

  a) 4 new bays at the new Lincolnshire Connection substation(s) and connections to the new converter stations.

11.4.3 Table 11.1 below sets out the capital costs for potential strategic option EGL OPP5:

Table 11.1 – Option EGL OPP5: capital cost for each technology option

Item	Need	EGL OPP5 Capital Cost	
Substation Works	Facilitate Generation and connect new circuits	£120.0m	
New Circuits		**AC Subsea Cable (565km)**	**Subsea HVDC (1026km)**
New Circuit	New Circuit across the B6,B7a and B8 system boundaries	£17,289.7m	£4,239.1m
Total Capital Cost		**£17,409.7m**	**£4,359.1m**

11.4.4 Table 11.2 below sets out the lifetime cost for the new circuit options, the lifetime costs are different for each circuit technology and are included as a differentiator between technologies. These costs are calculated using the methodology described in “Strategic options technical appendix 2020/2021 price base” Appendix D.

Table 11.2 – – Option EGL OPP5: lifetime cost for each technology option

Subsea Based Option	EGL OPP5 AC Subsea Cable	EGL OPP5 Subsea HVDC
Capital Cost of New Circuits	£17,289.7m	£4,239.1m
NPV of Cost of Losses over 40 years	£1,131.9m	£314.2m
NPV of Operation & Maintenance Costs over 40 Years	£101.9m	£117.2m
Lifetime Cost of New Circuits	**£18,524m**	**£4,670m**

11.5 Summary

11.5.1 EGL OPP5 comprises new transmission circuits from Peterhead, Aberdeenshire (EGL3) and Westfield, Fife (EGL4) connecting to a new Lincolnshire Connection substation. We note from the outputs of our appraisal that EGL OPP5 is close to the coast which reduces the extent of new infrastructure required onshore. Subject to sensitive routeing and siting, the environmental and socio-economic appraisal has not identified any factors which would significantly constrain or prevent this option.

11.5.2 EGL OPP5 would provide additional boundary capability on B6, B7a and B8 system boundaries but would also significantly increase loading on the proposed Grimsby West to Walpole reinforcement south of the Lincolnshire Connection substation(s). It should also be noted that this option would require further works to resolve B9 system boundary issues as well as being dependent upon the delivery of the new Lincolnshire Connection substation(s) and the new circuits required to connect it to the transmission system.

12. Appraisal of potential strategic option EGL OPP6 New Walpole Substation

12.1 Overview of OPP6

12.1.0 Option EGL OPP6 involves the development of new transmission circuits from Peterhead, Aberdeenshire (EGL3) and Westfield, Fife (EGL4) connecting to the new Walpole substation. A new Walpole substation is proposed as part of the Grimsby to Walpole reinforcement and:

- could be located anywhere between the existing Spalding North tee and the existing Walpole substation, and
- will be subject to an application for development consent in the future.

12.1.1 Due to the possible location of the new Walpole substation, landfall options on the Lincolnshire coastline and also the Norfolk coastline were considered as part of this appraisal.

12.1.2 For landfall options on the Lincolnshire coastline, the majority of the new circuits would be routed within the North Sea making landfall between the Humber and the Wash. The marine element for this Lincolnshire coastline landfall option is broadly similar to that of strategic options EGL OPP1 to 5. The main difference being where the landfall is located (i.e. how far south the submarine cables are routed).

12.1.3 For landfall options on the Norfolk coastline, the majority of the new circuits would be routed within the North Sea making landfall between Blakeney Point and Cromer. The marine element for this Norfolk coastline landfall option is broadly similar to that of strategic options EGL OPP1 to 5. The main difference being a need to extend south/south east of the Wash to make landfall on the Norfolk coastline.

12.1.4 The circuit distances for this connection are set out below. These are based on subsea cable route distances from a preliminary cable routeing study and the longest straight-line distance from a landfall on the Lincolnshire coastline to the new Walpole substation.

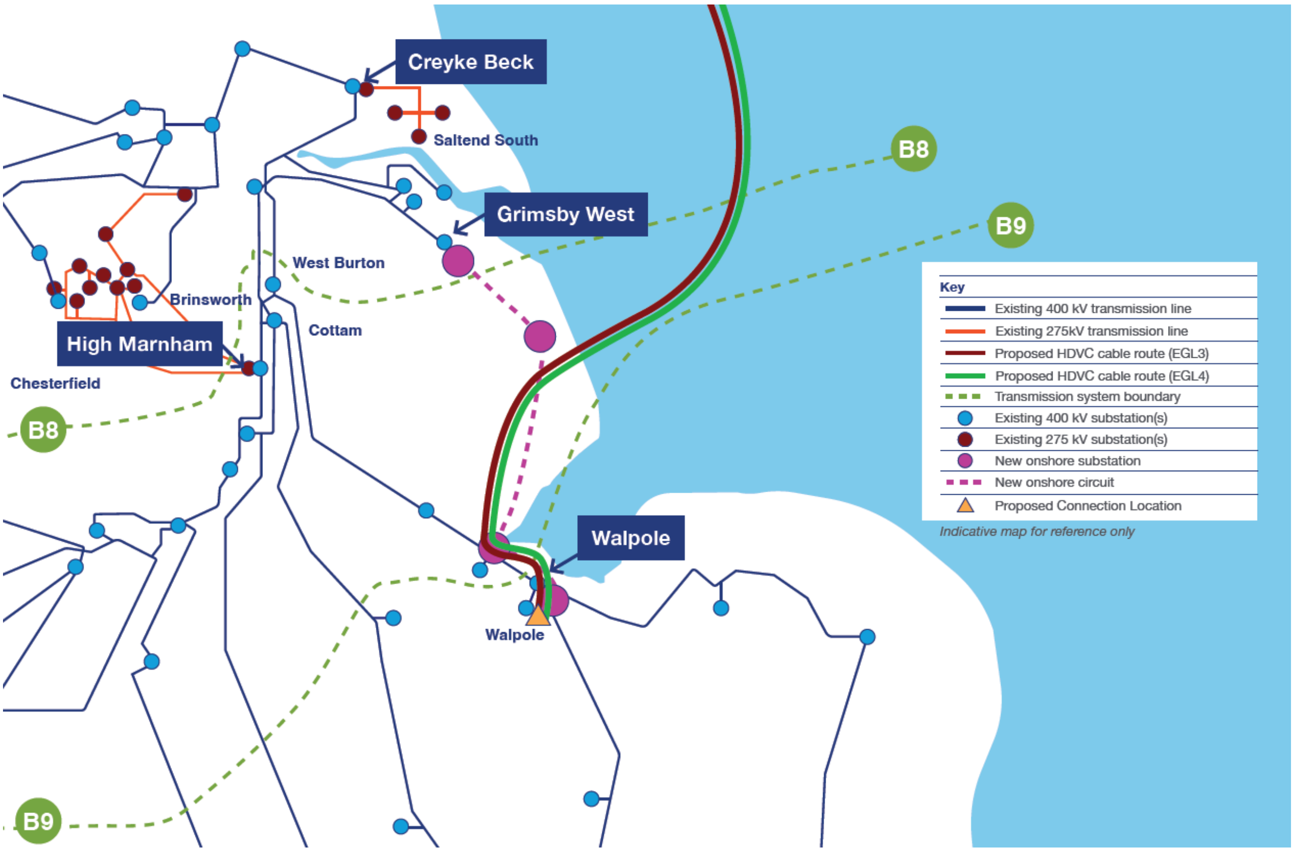
- EGL 3 640km
- EGL 4 536km
- Total combined distance 1176km

12.1.5 The distances for the Lincolnshire landfall point are used as the overall distance for this option, as it is the longer straight-line distance. However, the distances for a landfall on the Norfolk coastline are still within the 20% tolerance applied for potential route deviations, as mentioned in paragraph 6.1.3 above. As such, a separate appraisal of the Norfolk distance is not considered necessary.

12.1.6 This option is formed of two HVDC links which would require two pairs of two HVDC cables (i.e. 4 cables in total) as well as converter stations at either end of the links (one in Peterhead, one in Westfield and two converter stations at the new Walpole substation). This option would require two converter stations with an approximate footprint of 6 ha each (an indicative diagram is provided in Appendix C) as well as onshore underground HVDC cable routes of approximately 98 to 106 km depending on landfall selection. The new Walpole substation would also be required to accommodate the connection to the wider transmission system. The new Walpole substation is currently be evaluated as part of the Grimsby West to Walpole connection, however could alternatively be delivered as part of this project scope with no further dependencies.

12.1.7 Figure 12.1 below shows a diagram of the location of the EGL OPP6 New Walpole substation potential strategic option considered within this report.

Figure 12.1 – EGL OPP6 New Walpole Substation potential strategic option



12.2 Environmental and Socio-economic Appraisal

12.2.1 An environmental and socio-economic appraisal has been undertaken of two new transmission circuits making landfall on the Lincolnshire or Norfolk coastlines and connecting to the new Walpole substation in west Norfolk. This is because the overall route length is comparable i.e. a shorter subsea cable route to but longer underground cable from the Lincolnshire coastline, compared to a longer subsea cable route to and shorter underground cable from the Norfolk coastline.

Landfall option (a): Lincolnshire coastline

12.2.2 An environmental and socio-economic appraisal has been undertaken of two new transmission circuits making landfall on the Lincolnshire coast and connecting to the new Walpole Substation in west Norfolk.

12.2.3 For the purposes of the appraisal a study area was established in which the terrestrial elements of EGL3 and EGL4 (comprising underground cables and converter stations) could reasonably be expected to be developed. This extended from the Lincolnshire coastline (between south of Cleethorpes and north of Chapel St Leonards) inland to the point of connection at the new Walpole substation. The appraisal has also considered marine environmental and socio-economic factors in so far as they may be a differentiator between options, for example increased subsea cable route length in the marine environment and/or potentially impacting different or additional marine environmental or socio-economic considerations.

12.2.4 There are a number of statutory ecological designations present within the marine environment which could potentially be impacted subject to subsea cable routeing and landfall siting on the Lincolnshire coast. These include the Southern North Sea SAC, Greater Wash SPA, Holderness Inshore MCZ, Holderness Offshore MCZ and subject to how far south the landfall is located potentially also the Inner Dowsing, Race Bank and North Ridge SAC. However, these sites are common to any subsea cable route making landfall on the Lincolnshire coast and therefore are not a significant differentiator between the strategic options being assessed.

12.2.5 The Lincolnshire coastline is also subject to a number of statutory ecological designations. From north to south this includes the Humber Estuary SPA, SAC and SSSI, Saltfleetby-Theddlethorpe Dunes & Gibraltar Point SAC, Saltfleetby-Theddlethorpe Dunes SSSI and NNR and Donna Nook NNR as well as Sea Bank Clay Pits SSSI and Chapel Point to Wolla Bank SSSI. These sites are potentially avoidable through landfall selection. Where landfalls are located within coastal ecological designations, impacts may be avoided through a choice of cable installation methods (for example trenchless methods such as Horizontal Directional Drilling [HDD]) or adherence to seasonal working restrictions). As a result, coastal ecological designations are not considered to be a significant constraint on this option.

12.2.6 Environmental and socio-economic constraints influencing underground cable routes to the Walpole area are similar to those for Bicker Fen and Weston Marsh; the study area is not considered to be highly constrained in terms environmental designations. Part of the Lincolnshire Wolds AONB extends into the north of the study area close to the coast while the Wash SPA, SAC and SSSI lie to the south, however, these sites can be avoided with careful routeing. Subject to detailed routeing there may be some potential for disturbance and/or displacement impacts where qualifying bird species of the Wash SPA utilise adjacent agricultural land, however, this should be temporary for the duration of cable installation only.

12.2.7 There are a small number of SSSIs and scheduled monuments present within the area between the Lincolnshire coastline and the Walpole area but these designations occupy small areas and can be avoided with careful routeing therefore are not considered to materially influence this option.

12.2.8 Small and moderately sized settlements are present throughout the study area often coalescing along main transport routes including A16, A52 and A17. Boston is a key constraint and will influence the underground cable routeing and cable distances e.g. either north and west or south and east of the settlement. Similar applies to settlements along the A17, including Holbeach and Long Sutton which will influence the directness of routes to the Walpole area.

12.2.9 The majority of land within the study area comprises agricultural land with an Agricultural Land Capability classification of grade 1 or 2. This does not prevent cable routeing through these areas but highlights the need for effective soil management and reinstatement for underground cable routes to converter stations in the vicinity of the new Walpole substation.

12.2.10 There are a small number of statutory historic environment designations comprising grade I and II listed buildings in the Walpole area which could experience setting impacts subject to converter station siting including in combination with the new Walpole substation proposed as part of the Grimsby to Walpole reinforcement, however, existing electricity infrastructure is widely present in the area. The distribution of small settlements including Walpole St Andrew, Walpole St Peter, West Walton and Walton Highway as well as Wisbech may result in amenity related impacts, for example noise or visual impacts. Careful site selection and design including appropriate mitigation would be required in order to avoid or reduce potential impacts on settlements.

12.2.11 Overall, on the basis of the information currently available and assuming that appropriate mitigation is undertaken, together with sensitive routeing and siting, environmental and socio-economic factors are not considered to significantly constrain this option a.

Landfall option (b): Norfolk coastline

12.2.12 For the purposes of the appraisal a study area was established in which the terrestrial elements of EGL3 and EGL4 (comprising underground cables and converter stations) could reasonably be expected to be developed. This extended from the Norfolk coastline (between Blakeney Point and Cromer) inland to the point of connection at the new Walpole substation. The appraisal has also considered marine environmental and socio-economic factors in so far as they may be a differentiator between options, for example increased subsea cable route length in the marine environment and/or potentially impacting different or additional marine environmental or socio-economic considerations.

12.2.13 There are a number of statutory ecological designations present within the marine environment which could potentially be impacted subject to route and landfall selection. These include some sites which would also be impacted by strategic options making landfall in Lincolnshire (the Southern North Sea SAC, Greater Wash SPA, Holderness Inshore MCZ and Holderness Offshore MCZ Inner Dowsing, Race Bank and North Ridge SAC), but also includes additional sites which would be impacted by making landfall in Norfolk. These include the Wash & North Norfolk Coast SAC, North Norfolk Coast SPA, SAC and SSSI and Cromer Shoals MCZ. One or more of these sites would require to be crossed in order to make landfall on the Norfolk coast. While it would require to be confirmed through detailed survey and assessments, the qualifying features for the sites comprise habitat features or interests which could be affected by a subsea cable route and/or associated rock protection resulting in permanent habitat loss.

12.2.14 Underground cable routeing from the Norfolk coast to the Walpole area is more constrained compared to other options due to the presence of a range of statutory landscape, ecological and historic environment designations. The Norfolk Coast AONB extends across the coastline and study area and cannot be avoided. While long term impacts on the AONB should be limited as result of the use of underground cables, alternative options which can avoid it would be preferable, including in order to address planning policy requirements.

12.2.15 There are a range of other constraints present including SACs, SSSIs, scheduled monuments and Registered Parks and Gardens. While the majority of these designations are relatively small and avoidable with careful routeing, their distribution would affect the directness of potential underground cable routes and increase overall route lengths.

12.2.16 There are a number of settlements present within the study area ranging from small villages to market towns; larger settlements include Fakenham and King's Lynn. In combination with designated sites, the latter is likely to significantly influence route options requiring longer routes to south of King's Lynn and the A149/A17 in order to avoid potential impacts.

12.2.17 A large proportion of the study area comprises agricultural land with an Agricultural Land Capability classification of grade 3, however, west of King's Lynn towards the Walpole area this increases to grade 1 and 2. As with other strategic options routeing in high quality agricultural land is feasible, however, this assumes mitigation including effective soil management and reinstatement.

12.2.18 There are a small number of statutory historic environment designations comprising grade I and II listed buildings in the Walpole area which could experience setting impacts subject to converter station siting including in combination with the new Walpole substation proposed as part of the Grimsby to Walpole reinforcement, however, existing electricity infrastructure is widely present in the area. The distribution of small settlements including Walpole St Andrew, Walpole St Peter, West Walton and Walton Highway as well as Wisbech may result in amenity related impacts, for example noise or visual impacts. Careful site selection and design including appropriate mitigation would be required in order to avoid or reduce potential impacts on settlements.

12.2.19 Overall, on the basis of the information currently available and assuming that appropriate mitigation is undertaken, together with sensitive routeing and siting, the majority of environmental and socio-economic factors are not considered to significantly constrain this option b. However, due to the potential for this option b to impact on a number of statutory designated sites in the marine and terrestrial environments, compared to option a, option b is considered to be less preferable.

12.3 Technical Appraisal

12.3.1 Alongside the environmental and socio-economic appraisal of the option a technical appraisal has established that EGL OPP6 would satisfy the NETS SQSS and meet the requirements to resolve system boundaries B6, B7a and B8 (as stated in Part One of the need case). However, connection to the new Walpole substation would additionally connect below the B9 boundary and fully resolve Part Two of the need case.

12.3.2 Technical analysis of this option included consideration of the following:

- The option will significantly increase the loading on the existing circuits flowing south from the new Walpole substation, however this is the only option with multiple double circuits flowing south from the connection location.

12.4 Cost Appraisal

12.4.1 As set out in Section 6, we undertook a cost evaluation of the following two technologies for subsea options evaluation.

- 400 kV AC subsea cable
- 525 kV HVDC subsea cable

a) AC subsea connections circuit options use Med capacity double circuits (two 400 kV AC circuits) with a total capacity of up to 6380 mega volt amperes (MVA) of a distance of 640km. As we only require one AC double circuit cable we only consider this technology over the longest distance as we will pick up both Scottish connection points with the one double circuit AC connection then on to the connection point in England.; or

b) Subsea HVDC connection options use 525 kV 2 GW voltage source links, which would require a converter station at each end, similar in size to a large warehouse. In this case a 4 GW connection would require four converter stations in total, with up to two of the converters located at the new Walpole substation

c) Subsea HVDC cables totalling, EGL 3 – 640km and EGL 4 – 536km with total combined distance 1176km. The onshore HVDC cables to the connection point are included in this cost and distance.

- NGET Substation Works

a) 4 new bays at the new Walpole substation and connections to the converter stations.

12.4.2 **Table 12.1** below sets out the capital costs for potential strategic option EGL OPP6

Table 12.1 – Option EGL OPP6: capital cost for each technology option

Item	Need	EGL OPP6 Capital Cost	
Substation Works	Facilitate Generation and connect new circuits	£120.0m	
New Circuits		**AC Subsea Cable (640km)**	**Subsea HVDC**
New Circuit 1176 km	New Circuit across the B6,B7a, B8 and B9 system boundaries	£19,572.4m	£4,702.6m
Total Capital Cost		**£19,692.4m**	**£4,822.6m**

12.4.3 **Table 12.2** below sets out the lifetime cost for the new circuit options, the lifetime costs are different for each circuit technology and are included as a differentiator between technologies. These costs are calculated using the methodology described in "Strategic options technical appendix 2020/2021 price base" Appendix D.

Table 12.2 – Option EGL OPP6: lifetime cost for each technology option

Subsea Based Option	EGL OPP6 AC Subsea Cable	EGL OPP6 Subsea HVDC
Capital Cost of New Circuits	£19,572.4m	£4,702.6m
NPV of Cost of Losses over 40 years	£1,279.3m	£314.2m
NPV of Operation & Maintenance Costs over 40 Years	£115.0m	£117.6m
Lifetime Cost of New Circuits	**£20,967m**	**£5,134m**

12.5 Summary

12.5.0 EGL OPP6 comprises new transmission circuits from Peterhead, Aberdeenshire (EGL3) and Westfield, Fife (EGL4) connecting to the new Walpole substation. We note from the outputs of our technical appraisal that EGL OPP6 would provide additional boundary capability on B6, B7a and B8 system boundaries as well as the B9 system boundary. This option requires no further works to resolve B9 system boundary issues and the connection location has multiple circuits following south from the proposed connection.

12.5.1 For the environmental and socio-economic appraisal two possible landfall options for connecting to the new Walpole substation were considered. With a landfall on the Lincolnshire coastline, subject to sensitive routeing and siting, the outputs from our appraisal did not identify any factors which would significantly constrain or prevent this option. The option with a landfall on the Norfolk coastline, is considered to be significantly more constrained with regard to environmental constraints and potential impacts associated with subsea cable routeing. Therefore, an option with a landfall on the Norfolk coastline, is considered to be less preferable to an option with a landfall on the Lincolnshire coastline.

13. Appraisal of potential strategic option EGL OPP7 New Walpole substation with three ended HVDC link

13.1 Overview of OPP7

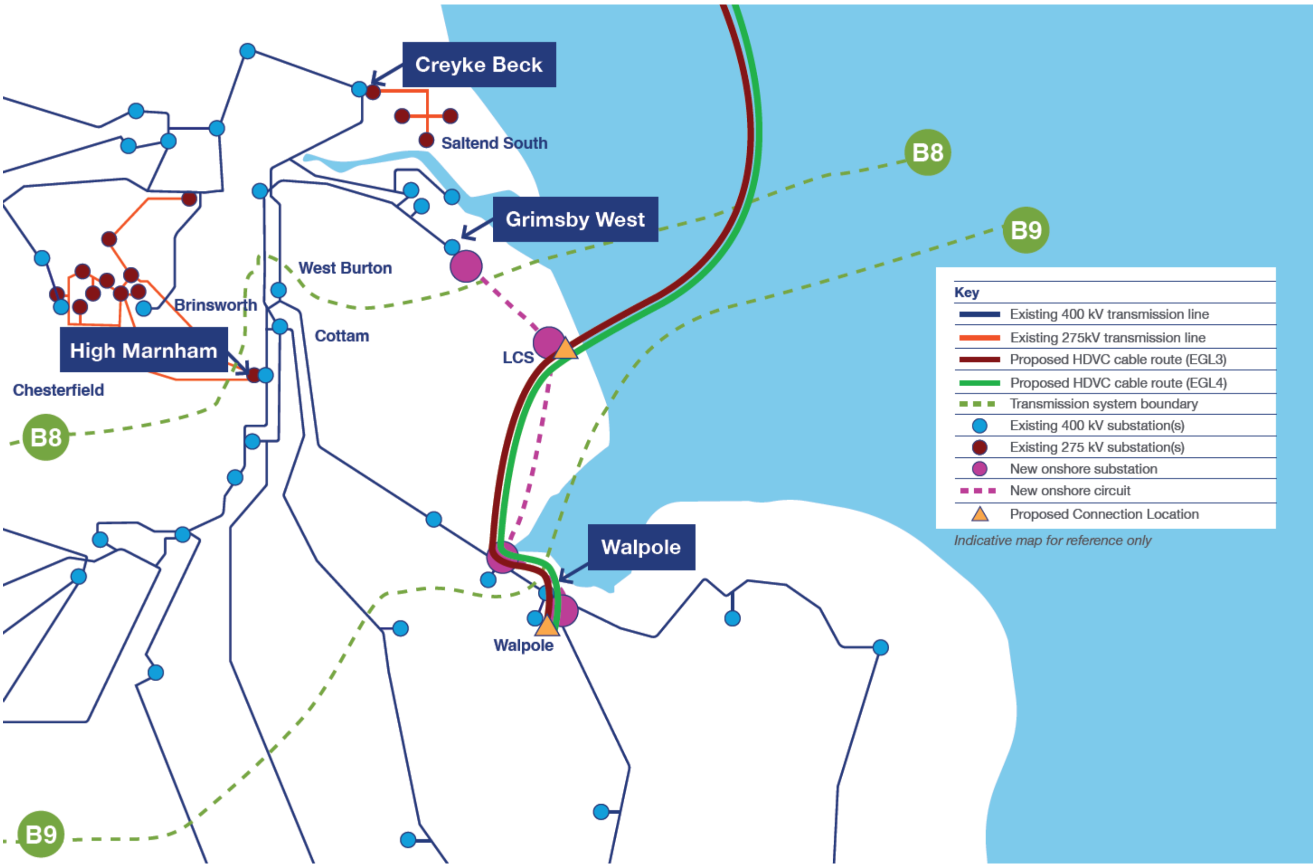
13.1.1 Option EGL OPP7 involves the development of new transmission circuits from Peterhead, Aberdeenshire (EGL3) and Westfield, Fife (EGL4) connecting to the new Walpole substation via a landfall on the Lincolnshire coastline, with one of the links also forming a three-ended link by connecting to the Lincolnshire Connection substation(s) first, before continuing to the new Walpole substation.

13.1.2 The option of making one of the links three ended would increase capacity from the new Lincolnshire Connection Substation(s) in the future, subject to the successful delivery of the Grimsby West to Walpole project and should the capacity be required in the future. Providing the capacity through the EGL infrastructure would increase capacity without the need for additional circuits in the near term from the Lincolnshire Connection Substation(s)

13.1.3 The majority of the new circuits would be routed within the North Sea making landfall on the Lincolnshire coastline between the Humber and the Wash. The marine element of EGL OPP7 is common to all strategic options with the main difference being where the landfall is located (i.e. how far south the submarine cables are routed). The new Walpole substation and the Lincolnshire Connection substation(s) are proposed as part of the Grimsby to Walpole project and therefore will subject to an application for development consent in the future. For the purposes of the appraisal of EGL OPP7, consideration has been given to the additional costs or impacts of extending the new Walpole and Lincolnshire Connection substations to connect EGL OPP7.

13.1.4 Figure 13.1 below shows a diagram of the location of the EGL OPP7 New Walpole substation with three ended HVDC link potential strategic option considered within this report.

Figure 13.1 – EGL OPP7 new Walpole substation with three ended HVDC link potential strategic option



13.1.5 The circuit distances for this connection are set out below. These are based on subsea cable route distances from a preliminary cable routeing study and the longest straight-line distance from a landfall on the Lincolnshire coastline to the new Walpole substation.

13.1.6 The circuit distances for this connection are as follows

- EGL 3 – 645km
- EGL 4 - 541km
- Total combined distance 1186km

13.1.7 This option would require five new converter stations with an approximate footprint of 6 ha each (an indicative diagram is provided in appendix C) as well as onshore underground HVDC cable routes of approximately 98 to 106 km depending on landfall selection. A new Walpole substation would also be required to accommodate the connection to the wider transmission system and one of the HVDC connections would also connect to the new Lincolnshire Connection substation(s).

13.1.8 The new Walpole substation could be located anywhere between the existing Spalding North tee and the existing Walpole substation. The new Walpole substation is currently be evaluated as part of the Grimsby West to Walpole project, however the new Walpole substation could alternatively be delivered as part of this project scope with no further dependencies.

13.1.9 The new Lincolnshire Connection Substation is subject to the delivery of the Grimsby West to Walpole project, including the required associate circuit connections.

13.1.10 To make one of the 2GW HVDC connections three ended, the HVDC circuit from Scotland would:

- loop into a new Lincolnshire Connection substation(s) (with a converter station located at this substation), then
- continue to the new Walpole substation (where a converter station would need to be located).

making a HVDC connection between Scotland, the new Lincolnshire Connection substation and the new Walpole substation.

13.1.11 For this strategic option, the other HVDC circuit connects directly from Scotland to the new Walpole substation (where another converter station would need to be located).

13.2 Environmental and Socio-economic Appraisal

13.2.1 An environmental and socio-economic appraisal has been undertaken of two new transmission circuits making landfall on the Lincolnshire coast and connecting to the new Walpole substation, with one of the links also connecting to the new Lincolnshire Connection substation(s) forming a three-ended HVDC link.

13.2.2 For the purposes of the appraisal a study area was established in which the terrestrial elements of EGL3 and EGL4 (comprising underground cables, converter stations and switching station) could reasonably be expected to be developed. This extended from the Lincolnshire coastline (between south of Cleethorpes and north of Chapel St Leonards) inland to points of connection at the Lincolnshire Connection substation(s) and Walpole substation. The environmental and socio-economic constraints or impacts influencing EGL OPP7 are the same as those described for EGL OPP5 (to Lincolnshire Connection substation) and EGL OPP6 (to the new Walpole substation). The appraisal has also considered marine environmental and socio-economic factors in so far as they may be a differentiator between options, for example increased subsea cable route length in the marine environment and/or potentially impacting different or additional marine environmental or socio-economic considerations.

13.2.3 There are a number of statutory ecological designations present within the marine environment which could potentially be impacted subject to subsea cable routeing and landfall siting on the Lincolnshire coast. These include the Southern North Sea SAC, Greater Wash SPA, Holderness Inshore MCZ, Holderness Offshore MCZ and subject to how far south the landfall is located the Inner Dowsing, Race Bank and North Ridge SAC. However, these sites are common to any subsea cable route making landfall on the Lincolnshire coast and therefore are not a significant differentiator between the strategic options being assessed.

13.2.4 The Lincolnshire coastline is also subject to a number of statutory ecological designations. From north to south this includes the Humber Estuary SPA, SAC and SSSI, Saltfleetby-Theddlethorpe Dunes & Gibraltar Point SAC, Saltfleetby-Theddlethorpe Dunes SSSI and NNR and Donna Nook NNR located as well as Sea Bank Clay Pits SSSI and Chapel Point to Wolla Bank SSSI. These sites are potentially avoidable through landfall selection. Where landfalls are located within coastal ecological designations, impacts may be avoided through a choice of cable installation methods (for example trenchless methods such as Horizontal Directional Drilling) or adherence to seasonal working restrictions). As result coastal ecological designations are not considered to be a significant constraint on this option.

13.2.5 Underground cable routeing towards the Lincolnshire Connection substation(s) is less constrained compared to other strategic options due its proximity to the coast and opportunities for shorter, more direct routes. There are fewer statutory ecological or historic environment designations in the area, however those which are present can be avoided with careful route and site selection.

13.2.6 Subject to site selection, the siting of a converter station and switching station connecting to the Lincolnshire Connection substation(s) in the rural/coastal area increases the potential for long-term effects on the setting of historic environment designations including scheduled monuments and listed buildings as well as the potential for long-term effects on views from within the Lincolnshire Wolds AONB. There is the potential to result in long term landscape and visual effects due to the introduction of new infrastructure in a landscape which currently has little major development. This includes the potential for cumulative effects in combination the Lincolnshire Connection substation(s) proposed as part of NGET's Grimsby to Walpole project. However, there may be some opportunities to mitigate this through site selection and design.

13.2.7 Underground cable route routeing towards a new Walpole substation is not considered to be highly constrained in terms environmental designations. Part of the Lincolnshire Wolds AONB extends into the north of the study area close to the coast while the Wash SPA, SAC and SSSI lie to the south, however, these sites can be avoided with careful routeing. Subject to detailed routeing there may be some potential for disturbance and/or displacement impacts where qualifying bird species of the Wash SPA utilise adjacent agricultural land, however, this should be temporary for the duration of cable installation only.

13.2.8 There are a small number of SSSIs and scheduled monuments present within the area between the Lincolnshire coastline and the Walpole area but these designations occupy small areas and can be avoided with careful routeing therefore are not considered to materially influence this option.

13.2.9 Small and moderately sized settlements are present throughout the study area often coalescing along main transport routes including A16, A52 and A17. Boston is a key constraint and will influence the underground cable routeing and cable distances e.g. either north and west or south and east of the settlement. Similar applies to settlements along the A17, including Holbeach and Long Sutton which will influence the directness of routes to the Walpole area.

13.2.10 The majority of land within the study area comprises agricultural land with an Agricultural Land Capability classification of grade 1 or 2. This does not prevent cable routeing through these areas but highlights the need for effective soil management and reinstatement for underground cable routes to converter stations in the vicinity of a new Walpole substation.

13.2.11 There are a small number of statutory historic environment designations comprising grade I and II listed buildings in the Walpole area which could experience setting impacts subject to converter station siting including in combination with the new Walpole substation proposed as part of NGET's Grimsby to Walpole project, however, existing electricity infrastructure is widely present in the area. The distribution of small settlements including Walpole St Andrew, Walpole St Peter, West Walton and Walton Highway as well as Wisbech may result in amenity related impacts, for example noise or visual impacts. Careful site selection and design including appropriate mitigation would be required in order to avoid or reduce potential impacts on settlements.

13.2.12 Overall, on the basis of the information currently available and assuming that appropriate mitigation is undertaken, together with sensitive routeing and siting, the majority of environmental and socio-economic factors are not considered to significantly constrain option EGL OPP7.

13.3 Technical Appraisal

13.3.1 Alongside the environmental and socio-economic appraisal of the option a technical appraisal has established that EGL OPP7 would satisfy the NETS SQSS and meet the requirements to resolve system boundaries B6, B7a and B8 (as stated in Part One of the need case). However, connection to the new Walpole substation would additionally connect below the B9 system boundary and fully resolve Part Two of the need case.

13.3.2 Technical analysis of this option included consideration of the following:

- The option will significantly increase the loading on the existing circuits flowing south from the new Walpole substation, however this is the only option with multiple double circuits flowing south from the connection location.
- This option will increase future capacity from the new Lincolnshire Connection substation(s) in the future (subject to the successful delivery of NGET's Grimsby to Walpole project and should the additional capacity be required).

13.4 Cost Appraisal

13.4.1 As set out in Section 6, we undertook a cost evaluation of the following two technologies for subsea options evaluation.

- 400 kV AC subsea cable
- 525 kV HVDC subsea cable

13.4.2 Option EGL OPP7 requires the following transmission works to satisfy the requirements of the NETS SQSS.

- New Circuit requirements

  a) AC subsea connections circuit options use Med capacity double circuits (two 400 kV AC circuits) with a total capacity of up to 6380 mega volt amperes (MVA) of a distance of 645km. As we only require one AC double circuit cable, we only consider this technology over the longest distance as we will pick up both Scottish connection points with the one double circuit AC connection then on to the connection point in England; or

  b) Subsea HVDC connection options use 525 kV 2 GW voltage source links, which would require a converter station at each end, similar in size to a large warehouse. In this case a 4 GW connection would require 5 converter stations in total, with up to two of the converters located at the new Walpole substation and one at the new Lincolnshire Connection substation(s) and two convertor stations at the Scottish connection locations.

  c) Subsea HVDC cables totalling, EGL 3 – 645km and EGL 4 – 541km with total combined distance 1186km. The onshore HVDC cables to the connection point are included in this cost and distance.

- NGET Substation Works
    a) 4 new bays at the new Walpole substation and connections to the converter stations.
    b) 2 new bays at new Lincolnshire Connection substation(s)

13.4.3 **Table 13.1** below sets out the capital costs for potential strategic option EGL OPP7:

Table 13.1 – Option EGL OPP7: capital cost for each technology option

<table>
<tr><th>Item</th><th>Need</th><th colspan="2">EGL OPP7 Capital Cost</th></tr>
<tr><td>Substation Works</td><td>Facilitate Generation and connect new circuits</td><td colspan="2">£180.0m</td></tr>
<tr><th>New Circuits</th><th></th><th>AC Subsea Cable (645km)</th><th>Subsea HVDC</th></tr>
<tr><td>New Circuit
1186 km</td><td>New Circuit across the B6,B7a, B8 and B9 system boundaries</td><td>£19,749.8m</td><td>£5,000.7m</td></tr>
<tr><td colspan="2">Total Capital Cost</td><td>£19,929.8m</td><td>£5,180.7m</td></tr>
</table>

13.4.4 **Table 13.2** below sets out the lifetime cost for the new circuit options, the lifetime costs are different for each circuit technology and are included as a differentiator between technologies. These costs are calculated using the methodology described in "Strategic options technical appendix 2020/2021 price base" Appendix D.

Table 13.2 – Option EGL OPP7: lifetime cost for each technology option

Subsea Based Option	EGL OPP7 AC Subsea Cable	EGL OPP7 Subsea HVDC
Capital Cost of New Circuits	£19,749.8m	£5,000.7m
NPV of Cost of Losses over 40 years	£1,294.1m	£392.7m
NPV of Operation & Maintenance Costs over 40 Years	£116.8m	£146.2m
Lifetime Cost of New Circuits	**£21,161m**	**£5,540m**

13.5 Summary

13.5.1 EGL OPP7 comprises new transmission circuits from Peterhead, Aberdeenshire (EGL3) and Westfield, Fife (EGL4) making landfall on the Lincolnshire coast and forming a three-ended link, between the Lincolnshire Connection substation(s) in East Lindsey and the new Walpole substation in west Norfolk. We note from the outputs of our technical appraisal, that EGL OPP7 would provide additional boundary capability on B6, B7a and B8 system boundaries as well as the B9 system boundary and would fully meet the need case. This option requires no further works to resolve B9 system boundary issues and the connection location has multiple circuits following south from the proposed connection.

13.5.2 This option will allow one of the HVDC connections to be made into a three ended HVDC link by looping into a new Lincolnshire Connection substation(s) with an associated HVDC converter station (subject to NGET's Grimsby Burton to Walpole project and associated circuits proceeding). This option will allow for future capacity from the new Lincolnshire Connection substation(s) to be increased subject to the need for additional capacity arising. Subject to sensitive routeing and siting, the environmental and socio-economic appraisal has not identified any factors which would significantly constrain or prevent this option.

14. Conclusion and Next Steps

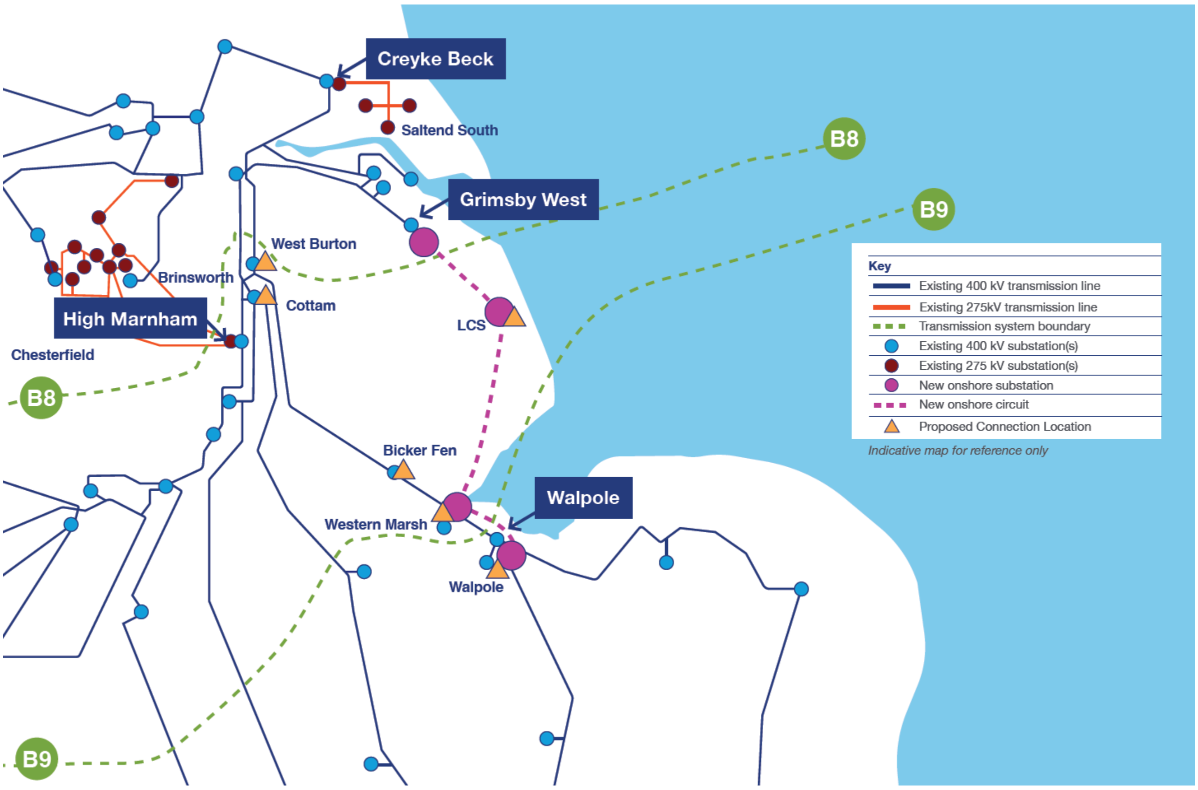
14.1 Introduction

14.1.1 As described in the need case for EGL3 and EGL4 (set out in Section 4), two issues were identified both of which need to be resolved:

- Part One: Provision of >10GW of capacity across the B6, B7a and B8 system boundaries
- Part Two: Provision of >6GW of capacity across the B9 system boundary and to provide resilience for future generation growth.

14.1.2 This report has considered options to meet the need case for EGL3 and EGL4. Figure 14.1 below shows a geographical indication of the six substation connection locations appraised as part of this report.

Figure 14.1 – Geographical indication of strategic options appraised



14.1.3 Seven potential strategic options were appraised by reference to environmental and socio-economic impacts, technical analysis, indicative capital and lifetime cost estimates.

14.1.4 Table 14.1 sets out the potential strategic options considered to connect the two new EGL3 and EGL4 HVDC links to NGET’s transmission system:

Table 14.1 – Potential Strategic Options for Connection of EGL3 and EGL4

Potential Strategic Option Reference Number	Potential Strategic Option	Estimated Circuit Length for		Estimated Total Circuit Length for Both HVDC Links
		EGL3 Connection	EGL4 Connection	
EGL OPP1	West Burton substation	625km	521km	**1146 km**
EGL OPP2	Cottam substation	655km	551km	**1206 km**
EGL OPP3	Bicker Fen substation	620km	516km	**1136 km**
EGL OPP4	New Weston Marsh substation	627km	523km	**1150km**
EGL OPP5	New Lincolnshire Connection substation(s)	565km	461km	**1026km**
EGL OPP6	New Walpole substation	640km	536km	**1176km**
EGL OPP7	New Walpole substation with three ended link	645km	541km	**1186km**

14.1.5 The findings of the options appraisal for these seven potential strategic options, which considered a range of technical, environmental, socio-economic and cost issues, are summarised below.

14.2 Environmental and socio-economic appraisal

14.2.1 One of the key conclusions of the environmental and socio-economic appraisals of the potential strategic options EGL OPP1 to EGL OPP7 was that all of the strategic options have the potential for environmental and socio-economic effects. Some of the effects identified are largely common to all of the potential strategic options, particularly in respect of the marine and coastal environment where subsea cables are routed and come ashore.

14.2.2 Each of the potential strategic options considered (EGL OPP1 to EGL OPP7) could make landfall on the Lincolnshire coastline. Subject to site selection for any of the potential strategic options making landfall on the Lincolnshire coast could impact on the same coastal ecological designations including the Humber Estuary SPA, SAC and SSSI, Saltfleetby-Theddlethorpe Dunes & Gibraltar Point SAC, Saltfleetby-Theddlethorpe Dunes SSSI and NNR and Donna Nook NNR located as well as Sea Bank Clay Pits SSSI and Chapel Point to Wolla Bank SSSI. These sites are all potentially avoidable, subject to landfall selection as well as cable installation methods (for example Horizontal Directional Drilling or adherence to seasonal working restrictions) so are not considered to constrain or differentiate between options.

14.2.3 As part of this appraisal, a landfall on the north Norfolk coastline for one strategic option (OPP6 – new Walpole substation via a landfall on the Norfolk coastline) was also appraised. Subsea cable routes are broadly north to south meaning that an option to the

Norfolk coastline crosses or potentially impacts on the same marine ecological designations as options to the Lincolnshire coastline. However, landfall on the Norfolk coastline also has the potential to impact on additional sites including the Wash & North Norfolk Coast SAC, North Norfolk Coast SPA, SAC and SSSI and Cromer Shoals MCZ.

14.2.4 The additional sites which could be impacted by the OPP6 (landfall via the Norfolk coastline) option include sites designated for habitat which may be permanently impacted by a subsea cable route and/or associated rock protection resulting in permanent habitat loss. For this reason, an option to Walpole via the north Norfolk coastline is considered to be more impacting than alternative options via the Lincolnshire coast. Therefore, potential strategic option EGL OPP6 (landfall via the Norfolk coastline) was less preferred for environmental reasons.

14.2.5 Our appraisal (of each potential strategic option), also considered potential effects in the area between an assumed landfall location and the relevant NGET substation (existing or planned). One of the key differentiators between the potential strategic options, relates to overall route length which can impact the extent of environmental and socio-economic effects.

14.2.6 Option EGL OPP 5 (Lincolnshire Connection substation(s)) is the closest option to the Lincolnshire coastline and would be expected to have lower environmental and socio-economic effects as a result of shorter, more direct underground cable routes. However, its proximity to the Lincolnshire Wolds AONB and the low-lying coastal hinterland means that converter stations in this area have the potential for long term effects on views from within the AONB as well as on landscape and visual more generally. This includes the potential for cumulative impacts on the AONB and landscape and visual interests in combination with the new Lincolnshire Connection substation(s). Subject to site selection there is also the potential for setting impacts on statutory historic environment designations including scheduled monuments and listed buildings. There would be some opportunities to mitigate effects on the AONB and setting of historic environment constraints through detailed siting and provision of landscape mitigation, for example to screen views from the AONB.

14.2.7 Options EGL OPP1 (West Burton) and EGL OPP2 (Cottam) would require long distance underground cable routes including a requirement to cross the Lincolnshire Wolds Area of Outstanding Natural Beauty (AONB). While assuming careful routeing and reinstatement, an underground cable route should not result in long term impacts on the designated landscape. However, it is preferable to avoid directly impacting the AONB where possible both in environmental terms and taking account of planning policy requirements.

14.2.8 Options EGL OPP3 (Bicker Fen), EGL OPP4 (Weston Marsh) and EGL OPP6 (Walpole via a landfall on Lincolnshire coast) are broadly comparable requiring long-distance underground cable routes through predominantly agricultural land. These options avoid or provide opportunities to mitigate impacts on internationally and nationally designated landscapes, ecological sites and historic environment features through careful route selection. Connections to the new Walpole substation will require long-distance underground cable routes through mainly agricultural land. Impacts on designated sites (landscape, ecology and historic environment) are avoidable with careful routeing.

14.2.9 Each of these three options would require converter station sites in rural areas with the potential for landscape and visual effects. While none are immediately adjacent to settlements or individual properties there are small villages in the vicinity of Bicker Fen and Walpole. There are designated historic environment assets within the vicinity of each of the sites; at Bicker Fen there is one scheduled monument and a small number of listed buildings, while at Weston Marsh and Walpole there are a small number of listed buildings. Subject to converter station siting there is the potential for setting impacts to occur for each option. Within the Walpole area the key constraints influencing converter station siting are setting impacts on designated historic environment assets and potential impacts on nearby settlements. At a strategic level, there are no significant environmental or socio-economic differentiators between these three options.

14.2.10 EGL OPP7 (new Walpole substation and three-ended link) which combines elements of EGL OPP5 (Lincolnshire Connection substation(s)) and EGL OPP6 (new Walpole substation via a landfall on the Lincolnshire coastline). Both HVDC links would connect to the new Walpole substation via two converter stations (one per HVDC link) and an additional HVDC link would connect to the Lincolnshire Connection substation(s) via a converter station and switching station. In general terms, because a three-ended link involves more infrastructure that the other potential strategic options it would be expected to have a greater environmental and socio-economic impact relative to the other options. However, there are opportunities to mitigate potential impacts through careful routeing and siting as well as more specific measures such as landscape planting.

14.2.11 Each of the options appraised have their relative advantages and disadvantages. A comparative analysis of the key findings of the environmental and socio-economic appraisal is provided in Table 14.2 below.

Table 14.2 – Summary of Environmental and Socio-economic Appraisal

Topic	EGL OPP1 West Burton Substation	EGL OPP2 Cottam Substation	EGL OPP3 Bicker Fen Substation	EGL OPP4 New Weston Marsh Substation	EGL OPP5 Lincolnshire Connection Substation (s)	EGL OPP6 New Walpole Substation (via a landfall on Lincolnshire coastline)	EGL OPP6 New Walpole Substation (via a landfall on Norfolk coastline)	EGL OPP7 New Walpole Substation with Three Ended Link
Biological Environment	Subject to subsea cable routeing and how far south the landfall is located there is the potential for effects on the Southern North Sea SAC, Greater Wash SPA, Holderness Inshore MCZ, Holderness Offshore MCZ and subject to how far south the landfall is located potentially also the Inner Dowsing, Race Bank and North Ridge SAC. Subject to landfall selection there is the potential for effects on the Humber Estuary SPA, SAC and SSSI, Saltfleetby-Theddlethorpe Dunes & Gibraltar Point SAC, Saltfleetby-Theddlethorpe Dunes SSSI and NNR and Donna Nook NNR as well as Sea Bank Clay Pits SSSI and Chapel Point to Wolla Bank SSSI.	Subject to subsea cable routeing and how far south the landfall is located there is the potential for effects on the Southern North Sea SAC, Greater Wash SPA, Holderness Inshore MCZ, Holderness Offshore MCZ and subject to how far south the landfall is located potentially also the Inner Dowsing, Race Bank and North Ridge SAC. Subject to landfall selection there is the potential for effects on the Humber Estuary SPA, SAC and SSSI, Saltfleetby-Theddlethorpe Dunes & Gibraltar Point SAC, Saltfleetby-Theddlethorpe Dunes SSSI and NNR and Donna Nook NNR as well as Sea Bank Clay Pits SSSI and Chapel Point to Wolla Bank SSSI.	Subject to subsea cable routeing and how far south the landfall is located there is the potential for effects on the Southern North Sea SAC, Greater Wash SPA, Holderness Inshore MCZ, Holderness Offshore MCZ and subject to how far south the landfall is located potentially also the Inner Dowsing, Race Bank and North Ridge SAC. Subject to landfall selection there is the potential for effects on the Humber Estuary SPA, SAC and SSSI, Saltfleetby-Theddlethorpe Dunes & Gibraltar Point SAC, Saltfleetby-Theddlethorpe Dunes SSSI and NNR and Donna Nook NNR as well as Sea Bank Clay Pits SSSI and Chapel Point to Wolla Bank SSSI.	Subject to subsea cable routeing and how far south the landfall is located there is the potential for effects on the Southern North Sea SAC, Greater Wash SPA, Holderness Inshore MCZ, Holderness Offshore MCZ and subject to how far south the landfall is located potentially also the Inner Dowsing, Race Bank and North Ridge SAC. Subject to landfall selection there is the potential for effects on the Humber Estuary SPA, SAC and SSSI, Saltfleetby-Theddlethorpe Dunes & Gibraltar Point SAC, Saltfleetby-Theddlethorpe Dunes SSSI and NNR and Donna Nook NNR as well as Sea Bank Clay Pits SSSI and Chapel Point to Wolla Bank SSSI.	Subject to subsea cable routeing and how far south the landfall is located there is the potential for effects on the Southern North Sea SAC, Greater Wash SPA, Holderness Inshore MCZ, Holderness Offshore MCZ and subject to how far south the landfall is located potentially also the Inner Dowsing, Race Bank and North Ridge SAC. Subject to landfall selection there is the potential for effects on the Humber Estuary SPA, SAC and SSSI, Saltfleetby-Theddlethorpe Dunes & Gibraltar Point SAC, Saltfleetby-Theddlethorpe Dunes SSSI and NNR and Donna Nook NNR as well as Sea Bank Clay Pits SSSI and Chapel Point to Wolla Bank SSSI.	Subject to subsea cable routeing and how far south the landfall is located there is the potential for effects on the Southern North Sea SAC, Greater Wash SPA, Holderness Inshore MCZ, Holderness Offshore MCZ and subject to how far south the landfall is located potentially also the Inner Dowsing, Race Bank and North Ridge SAC. Subject to landfall selection there is the potential for effects on the Humber Estuary SPA, SAC and SSSI, Saltfleetby-Theddlethorpe Dunes & Gibraltar Point SAC, Saltfleetby-Theddlethorpe Dunes SSSI and NNR and Donna Nook NNR as well as Sea Bank Clay Pits SSSI and Chapel Point to Wolla Bank SSSI.	Subject to subsea cable routeing and how far south the landfall is located there is the potential for effects on the Southern North Sea SAC, Greater Wash SPA, Holderness Inshore MCZ, Holderness Offshore MCZ, the Inner Dowsing, Race Bank and North Ridge SAC, Wash & North Norfolk Coast SAC, North Norfolk Coast SPA, SAC and SSSI and Cromer Shoals MCZ. Subject to landfall selection there is the potential for effects on the Wash & North Norfolk Coast SAC, North Norfolk Coast SPA, SAC and SSSI and Cromer Shoals MCZ. One or more of these sites would require to be crossed in order to make landfall on the Norfolk coast.	Subject to subsea cable routeing and how far south the landfall is located there is the potential for effects on the Southern North Sea SAC, Greater Wash SPA, Holderness Inshore MCZ, Holderness Offshore MCZ and subject to how far south the landfall is located potentially also the Inner Dowsing, Race Bank and North Ridge SAC. Subject to landfall selection there is the potential for effects on the Humber Estuary SPA, SAC and SSSI, Saltfleetby-Theddlethorpe Dunes & Gibraltar Point SAC, Saltfleetby-Theddlethorpe Dunes SSSI and NNR and Donna Nook NNR as well as Sea Bank Clay Pits SSSI and Chapel Point to Wolla Bank SSSI.
Physical Environment	This option will require underground routes crossing multiple main rivers and maintained drains as well as routeing through flood zones 2 and 3. Subject to converter station site selection flood zone 2 and 3 may be avoidable.	This option will require underground routes crossing multiple main rivers and maintained drains as well as routeing through flood zones 2 and 3. Flood zones 2 and 3 are likely to be unavoidable for converter station siting.	This option will require underground routes crossing multiple main rivers and maintained drains as well as routeing through flood zones 2 and 3. Subject to converter station siting flood zone 3 is avoidable, however, flood zone 2 is unavoidable.	This option will require underground routes crossing multiple main rivers and maintained drains as well as routeing through flood zones 2 and 3. Flood zones 2 and 3 are likely to be unavoidable for converter station siting.	Subject to landfall location underground cable routes will require to cross main rivers as well as routeing through flood zones 2 and 3. Flood zones 2 and 3 are likely to be unavoidable for converter station siting.	This option will require underground routes crossing multiple main rivers and maintained drains as well as routeing through flood zones 2 and 3. Flood zones 2 and 3 are likely to be unavoidable for converter station siting.	This option will require underground routes crossing multiple main rivers and maintained drains as well as routeing through flood zones 2 and 3. Flood zones 2 and 3 are likely to be unavoidable for converter station siting.	This option will require underground routes crossing multiple main rivers and maintained drains as well as routeing through flood zones 2 and 3. Flood zones 2 and 3 are likely to be unavoidable for converter station and switching station siting.

Topic	EGL OPP1 West Burton Substation	EGL OPP2 Cottam Substation	EGL OPP3 Bicker Fen Substation	EGL OPP4 New Weston Marsh Substation	EGL OPP5 Lincolnshire Connection Substation (s)	EGL OPP6 New Walpole Substation (via a landfall on Lincolnshire coastline)	EGL OPP6 New Walpole Substation (via a landfall on Norfolk coastline)	EGL OPP7 New Walpole Substation with Three Ended Link
Landscape and Visual	This option would require underground cable routes crossing of the Lincolnshire Wolds AONB. While long term effects are unlikely to occur assuming careful routeing and reinstatement it is preferable to avoid the AONB where possible.	This option would require underground cable routes crossing of the Lincolnshire Wolds AONB. While long term effects are unlikely to occur assuming careful routeing and reinstatement it is preferable to avoid the AONB where possible.	Potential effects on visual amenity on residents in settlements or in scattered properties in the vicinity of converter stations.	Potential effects on visual amenity on residents in settlements or in scattered properties in the vicinity of converter stations.	While the Lincolnshire Wolds AONB can be avoided there is the potential for impacts on its setting and from views within it as a result of the converter stations being located in a landscape in which there is little major development. Potential effects on visual amenity on residents in settlements or in scattered properties in the vicinity of converter stations.	Potential effects on visual amenity on residents in settlements or in scattered properties in the vicinity of converter stations.	The option would require landfalls and onwards underground cable routes within and crossing the Norfolk Coast AONB. While long term effects are unlikely to occur assuming careful routeing and reinstatement it is preferable to avoid the AONB where possible. Potential effects on visual amenity on residents in settlements or in scattered properties in the vicinity of converter stations.	While the Lincolnshire Wolds AONB can be avoided there is the potential for impacts on its setting and from views within it as a result of the converter station and switching station being located in a landscape in which there is little major development. Potential effects on visual amenity on residents in settlements or in scattered properties in the vicinity of converter stations and the switching station.
Historic Environment	While designated heritage assets are likely to be avoidable there is the potential for significant impacts on the setting of scheduled monuments and listed buildings subject to converter station siting.	While designated heritage assets are likely to be avoidable there is the potential for significant impacts on the setting of scheduled monuments and listed buildings subject to converter station siting.	While designated heritage assets are likely to be avoidable there is the potential for significant impacts on the setting of scheduled monuments and listed buildings subject to converter station siting.	While designated heritage assets are likely to be avoidable there is the potential for significant impacts on the setting of scheduled monuments and listed buildings subject to converter station siting.	While designated heritage assets are likely to be avoidable there is the potential for significant impacts on the setting of scheduled monuments and listed buildings subject to converter station siting.	While designated heritage assets are likely to be avoidable there is the potential for significant impacts on the setting of listed buildings in the vicinity of Walpole subject to converter station siting.	While designated heritage assets are likely to be avoidable there is the potential for significant impacts on the setting of listed buildings in the vicinity of Walpole subject to converter station siting.	While designated heritage assets are likely to be avoidable there is the potential for significant impacts on the setting of listed buildings in the vicinity of Walpole subject to converter station siting.
Settlement and Population	There are numerous small and moderate sized settlements scattered throughout the study area, however, these are likely to be avoidable assuming careful routeing.	There are numerous small and moderate sized settlements scattered throughout the study area, however, these are likely to be avoidable assuming careful routeing.	There are numerous small and moderate sized settlements scattered throughout the study area, however, these are likely to be avoidable assuming careful routeing.	There are numerous small and moderate sized settlements scattered throughout the study area, however, these are likely to be avoidable assuming careful routeing. Larger settlements such as Boston combine with other constraints to create pinch points which will influence route options.	There are a number of small settlements scattered throughout the study area, however, these are likely to be avoidable assuming careful routeing.	There are numerous small and moderate sized settlements scattered throughout the study area, however, these are likely to be avoidable assuming careful routeing. Larger settlements such as Boston combine with other constraints to create pinch points which will influence route options.	There are numerous small and moderate sized settlements scattered throughout the study area, however, these are likely to be avoidable assuming careful routeing. Larger settlements such as King's Lynn combine with other constraints to create pinch points which will influence route options.	There are numerous small and moderate sized settlements scattered throughout the study area, however, these are likely to be avoidable assuming careful routeing. Larger settlements such as Boston combine with other constraints to create pinch points which will influence route options.

Topic	EGL OPP1 West Burton Substation	EGL OPP2 Cottam Substation	EGL OPP3 Bicker Fen Substation	EGL OPP4 New Weston Marsh Substation	EGL OPP5 Lincolnshire Connection Substation (s)	EGL OPP6		EGL OPP7 New Walpole Substation with Three Ended Link
						New Walpole Substation (via a landfall on Lincolnshire coastline)	New Walpole Substation (via a landfall on Norfolk coastline)	
Infrastructure and land Use	Underground cable routes will require multiple road and rail crossings. Much of the land to be crossed by underground cable routes comprises agricultural land with an Agricultural Land Capability classification of grade 2 or 3. There are proposals for large scale solar farms in the vicinity of West Burton that may affect cable routeing and converter station siting.	Underground cable routes will require multiple road and rail crossings. Much of the land to be crossed by underground cable routes comprises agricultural land with an Agricultural Land Capability classification of grade 2 or 3. There are proposals for large scale solar farms in the vicinity of Cottam that may affect cable routeing and converter station siting.	Underground cable routes will require multiple road and rail crossings. Much of the land to be crossed by underground cable routes comprises agricultural land with an Agricultural Land Capability classification of grade 1 or 2.	Underground cable routes will require multiple road and rail crossings. Much of the land to be crossed by underground cable routes comprises agricultural land with an Agricultural Land Capability classification of grade 1 or 2.	Underground cable routes will require multiple road and rail crossings. Much of the land to be crossed by underground cable routes comprises agricultural land with an Agricultural Land Capability classification of grade 3.	Underground cable routes will require multiple road and rail crossings. Much of the land to be crossed by underground cable routes comprises agricultural land with an Agricultural Land Capability classification of grade 1 or 2.	Underground cable routes will require multiple road and rail crossings. Much of the land to be crossed by underground cable routes comprises agricultural land with an Agricultural Land Capability classification of grade 1 or 2.	Underground cable routes will require multiple road and rail crossings. Much of the land to be crossed by underground cable routes comprises agricultural land with an Agricultural Land Capability classification of grade 1 or 2.

14.3 Technical appraisal

14.3.1 Whilst each of options EGL OPP(1 to 5) satisfy issue Part One of the need case, these options would not satisfy Part Two of the need case as none of the options cross the B9 system boundary. This would require additional works for all of these options to provide additional B9 system boundary capacity.

14.3.2 Either of options EGL OPP(6 or 7) are the only options that satisfy without additional reinforcement works, both parts of the need case as the connections of the two new HVDC links would be below the B9 system boundary and alongside the proposed Grimsby West to Walpole connection would resolve the current system need.

14.3.3 EGL OPP7 would provide more additional transmission system capability than EGL OPP6 in the case that the Grimsby West to Walpole connection and associated circuits progresses. EGL OPP7 (Walpole substation with a three ended link) would provide additional future capacity in this area across the B9 system boundary without the need for alternative transmission system reinforcements.

14.3.4 Connections made above the B9 system boundary would require additional reinforcements to enable the connection of EGL3 and EGL4. The ESO's NOA initially indicated for example if connection were made to the new Weston Marsh or new Lincolnshire Connection substation(s), the projects would be dependent upon the delivery of NGET's Grimsby to Walpole project. They would also require the a new circuit across the B9 system boundary a distance of 90km from the Lincolnshire Connection as described in Chapter 16 of the North Humber to High Marnham and Grimsby West to Walpole SOR

14.4 Cost appraisal

14.4.1 An overview of the capital and lifetime cost impacts of each option is set out in Table 17.3. These may be summarised as follows:

- EGL OPP 1: capital cost of £4,729.9m and lifetime circuit cost of £5,042.0m;
- EGL OPP 2: capital cost of £4,915.3m and lifetime circuit cost of £5,227.0m;
- EGL OPP 3: capital cost of £4,699.0m and lifetime circuit cost of £5,011.0m;
- EGL OPP 4: capital cost of £4,742.3m and lifetime circuit cost of £5,054.0m;
- EGL OPP 5: capital cost of £4,359.1m and lifetime circuit cost of £4,670.0m;
- EGL OPP 6: capital cost of £4,822.6m and lifetime circuit cost of £5,134.0m; and
- EGL OPP 7: capital cost of £5,120.7m and lifetime circuit cost of £5,540.0m

14.4.2 Table 14.3 below sets out an overview of the capital and lifetime cost impacts of each alternative:

Table 14.3 – Capital and lifetime cost impact

Option	EGL OPP 1	EGL OPP 2	EGL OPP 3	EGL OPP 4	EGL OPP 5	EGL OPP 6	EGL OPP 7	Differential between EGL options
	West Burton substation	Cottam substation	Bicker Fen substation	New Weston Marsh substation	New Lincolnshire Connection substation(s)	New Walpole substation	New Walpole substation with one HVDC link three Ended to Lincolnshire Connection substation(s)	
	EGL 3 = 625km	EGL 3 = 655km	EGL 3 = 620km	EGL 3 = 627km	EGL 3 = 565km	EGL 3 = 640km	EGL 3 = 645km	
	EGL 4 = 521km	EGL 4 = 551km	EGL 4 = 516km	EGL 4 = 523km	EGL 4 = 461km	EGL 4 = 536km	EGL 4 = 541km	
	Total = 1146km	Total = 1206km	Total = 1136km	Total = 1150km	Total = 1026km	Total = 1176km	Total = 1186km	
Contribution to B6 system boundary capacity	4GW	4GW	4GW	4GW	4GW	4GW	4GW	**0GW**
Contribution to B7a system boundary capacity	4GW	4GW	4GW	4GW	4GW	4GW	4GW	**0GW**
Contribution to B8 system boundary capacity	4GW	4GW	4GW	4GW	4GW	4GW	4GW	**0GW**
Contribution to B9 system boundary capacity	0	0	0	0	0	4GW	4GW	**4GW**
B9 system boundary reinforcement required	Y	Y	Y	Y	Y	N	N	**EGL OPP 6 and 7 Don't require Lincolnshire section of LRN4**
Capital Cost including non-circuit works	£4,729.9m	£4,915.3m	£4,699.0m	£4,742.3m	£4,359.1m	£4,822.6m	£5,180.7m	**£761.6m difference between lowest and highest option**
(Difference from EGL OPP 5 Baseline cost)	-£370.80	-£556.20	-£339.90	-£383.20	(Baseline)	-£463.50	-£821.60	
Circuit 40yr Lifetime NPV Cost	£5,042.0m	£5,227.0m	£5,011.0m	£5,054.0m	£4,670.0m	£5,134.0m	£5,540.0m	**£870m difference between lowest and highest option**
(Difference from EGL OPP 5 Baseline cost)	-£372.00	-£557.00	-£341.00	-£384.00	(Baseline)	-£464.00	-£870.00	

14.4.3 Under the terms of the Transmission Licence, NGET is required to provide an efficient, economic and co-ordinated transmission system in England and Wales. NGET's transmission investment proposals are scrutinised by our regulator Ofgem.

14.4.4 Interaction with other projects that are expected to connect above the B9 system boundary (especially to any of the new Lincolnshire Connection substation(s), Bicker Fen or new Weston Marsh substations), would drive the need for an additional circuit in Lincolnshire. Table 14.2 sets out that an option (single or in combination) that would resolve both parts of the need case (set out In Section 4), would have to be selected to fully address the transmission system reinforcement requirements.

14.5 Comparative appraisal results

14.5.1 The option selected is required to address the need case, provide the best economic solution and meet our transmission licence obligations. We consider that pursuing the option identified in the conclusions set out below would meet our obligations under the transmission licence.

14.5.2 Based on the outputs from our comparative appraisal of two possible landfall options for EGL OPP6, the option to the new Walpole substation via a landfall on the Norfolk coastline was considered to be more impacting than the option via a landfall on the Lincolnshire coastline.

14.5.3 For each of EGL OPP1 (West Burton) and EGL OPP2 (Cottam) and EGL OPP6 (new Walpole substation landfall on the Norfolk coastline) additional statutory designations were identified which could be impacted on. Potential strategic options EGL OPP1, EGL OPP2 and EGL OPP6 (landfall via the Norfolk coastline) are therefore less preferable for environmental reasons.

14.5.4 In environmental terms, the other potential strategic options are broadly comparable (except with regard to length of cable route required) the potential impact on statutory designations is mainly limited to the marine route/landfall and therefore common to all options.

14.5.5 One of the key differentiators between options relates to overall route length which can impact the extent of environmental and socio-economic effects. Reflecting the location of each of NGET's substation (existing or planned), the total route length for each of the EGL3 and EGL4 potential strategic options ranged between 1,026km (EGL OPP5) and 1,206km (EGL OPP2).

14.5.6 EGL OPP5 (new Lincolnshire Connection Substation(s)) would require the shortest cable route length. EGL OPP1 (West Burton) and EGL OPP2 (Cottam) both require long distance routes either crossing the AONB or requiring even longer routes to avoid it. While impacts on the AONB would be temporary, alternative options which can avoid it would be preferable, including in order to address planning policy requirements.

14.5.7 Each of EGL OPP3 (Bicker Fen substation), EGL OPP4 (new Weston Marsh substation) and EGL OPP6 (new Walpole substation via a landfall on the Lincolnshire coastline) are comparable in terms of requiring long distance cable routes and converter stations in otherwise predominantly rural areas. EGL OPP6 has a slightly longer route, and therefore more impacts would be expected. However, due to the nature of the constraints which are/are not present, the impacts associated with EGL OPP6 are not considered to be materially different to or greater than, the impacts of going to Bicker Fen substation or the new Weston Marsh substation.

14.5.8 The findings from this appraisal (set out in Table 14.2), show option EGL OPP5 which requires the shortest cable route length, as a lowest cost option for the connection of EGL3 and EGL4 to NGET's transmission system. However, EGL OPP5 only satisfies Part One of the need case. Additional transmission reinforcement works (e.g a new section of the LRN4 circuit in Lincolnshire) would be required to resolve Part Two of the need case.

14.5.9 Noting that some potential strategic options address both Part One and Part Two of the need case for EGL3 and EGL4, as set out in Chapter 16 of the North Humber to High Marnham and Grimsby West to Walpole SOR, for comparison purposes, an indicative, circuit only, cost for the additional Lincolnshire circuit was estimated as a:

- capital cost of £358.2m, and
- lifetime cost of £616m.

14.5.10 The additional reinforcement works would need to be carried out in addition to any of options EGL OPP 1 to EGL OPP 5 to fully resolve both parts of the need case.

Table 14.4 – Cost estimates for transmission works that address both parts of the need case

Potential Strategic Option	Capital cost estimate £	Lifetime cost estimate £	Additional Works Required to meet Part Two of the need case	Total Cost to meet both parts of the need case	
				Capital cost estimate £	Lifetime cost estimate £
EGL OPP5 Lincolnshire Connection substation(s)	4,359.1m	4,670.0m	Yes	**4,717.3m**	**5,286m**
EGL OPP6 New Walpole substation	4,822.6m	5,134m	No	**4,822.6m**	**5,134m**

14.5.11 From this high level assessment of costs, whilst the capital cost estimate for EGL OPP6 (new Walpole substation via landfall on the Lincolnshire coastline) is circa £100m higher than option EGL OPP5, the lifetime cost estimate for EGL OPP6 is circa £150m lower than option EGL OPP5.

14.5.12 The lowest cost option to fully resolve the need case, is EGL OPP6 (a connection of the two new HVDC links to the new Walpole substation via a landfall on the Lincolnshire coastline), with estimates of a capital cost £4,822.6m and lifetime cost of £5,134m.

14.6 Conclusion

14.6.1 We consider that the conclusions set out below would meet our obligations under the transmission licence.

14.6.2 In summary, to address the need case (set out in Section 4) and considering the outputs from our appraisal of environmental, socio-economic, technical and cost differentiators, NGET is proposing to take forward option EGL OPP6 (new Walpole substation via a landfall on Lincolnshire coastline).

14.6.3 NGET proposes to develop EGL3 and EGL4 as two new 2GW HVDC cable connections (each of which is primarily subsea, with a land-based route in England from a landfall on the Lincolnshire coastline), with one converter station per circuit which is located in the vicinity of and connected to the new Walpole substation.

14.6.4 There is not a current requirement to provide a three ended connection to Lincolnshire Connection substation(s) (as described in EGL OPP7), to meet the need case for EGL3 and EGL4. However, NGET considers that the option developed for EGL3 and EGL4, should have the ability to be changed to provide a three ended connection to the Lincolnshire Connection substation(s) in the future should additional capacity be required. This would allow the HVDC connection to be extended via a three ended subsea solution to the Lincolnshire Connection substation(s) economically and facilitate transferring power below the B9 system boundary should the need arise.

14.6.5 A three ended link could play multiple roles in facilitating flows from both Scotland and Lincolnshire across the B9 system boundary during different fault conditions. This type of three ended link would be expected to offer additional flexibility within the transmission system, which could allow more generation to connect to Lincolnshire which would be a major advantage if/when additional connection requests are received.

14.6.6 This has been assigned the project title of ‘Eastern Green Link 3 and 4’. The EGL3 and EGL4 connection projects will now be taken forward to the next stage of development. This involves identification of a preliminary cable corridor and graduated swathe, which indicates a more likely location for the development. This will be consulted on at non statutory consultation, to seek feedback from consultees and help shape the further development of the projects.

Appendix

Appendix A: Summary of National Grid Electricity Transmission Legal Obligations

1.1 Electricity Transmission Licence

1.1.1 The Electricity Act 1989 (the 'Electricity Act') defines transmission of electricity within GB and its offshore waters, as a prohibited activity, which cannot be carried out without permission by a transmission licence granted under Section 6(1)(b) of the Electricity Act (a 'Transmission Licence').

1.1.2 National Grid Electricity Transmission ('National Grid') has been granted a Transmission Licence that permits transmission owner activities in respect of the electricity transmission system National Grid owns, develops and maintains in England and Wales.

1.1.3 Each Transmission Licence includes conditions which define the scope of the permission granted to carry out a prohibited activity in terms of duties, obligations, restrictions and rights. The generic conditions that apply to any holder of a Transmission Owner licence type are set out in Sections A, B and D of the Standard Conditions of the Transmission Licence. Conditions that only apply to a specific licensee are set out as Special Conditions of that Transmission Licence.

1.1.4 National Grid is therefore bound by the legal obligations primarily set out in the Electricity Act and its Transmission Licence. The following list provides a summary overview of requirements that are considered when developing proposals to construct new transmission system infrastructure.

1.2 Electricity Act Duties

1.2.1 In accordance with Section 9 of the Electricity Act, National Grid is required to develop and maintain an efficient, coordinated and economical system of electricity transmission.

1.2.2 Schedule 9 of the Electricity Act requires National Grid, when formulating proposals for new lines and other works, to:

"…have regard to the desirability of preserving natural beauty, of conserving flora, fauna, and geological or physiographical features of special interest and of protecting sites, buildings and objects of architectural, historic or archaeological interest; and to do what [it] reasonably can to mitigate any effect which the proposals would have on the natural beauty of the countryside or on any such flora, fauna, features, sites, buildings or objects".

1.2.3 National Grid's Stakeholder, Community and Amenity Policy ('the Policy') sets out how the company will meet this Schedule 9 duty. The commitments within the Policy include:

- only seeking to build new lines and substations where the existing transmission infrastructure cannot be upgraded technically or economically to meet transmission security standards;

- where new infrastructure is required, seeking to avoid areas that are nationally or internationally designated for their landscape, wildlife or cultural significance, and
- minimising the effects of new infrastructure on other sites valued for their amenity.

1.2.4 The Policy also refers to the application of best practice methods to assess the environmental impacts of proposals and identify appropriate mitigation and/or offsetting measures. Effective consultation with stakeholders and the public is also promoted by the Policy.

1.3 National Grid's Transmission Licence Requirements

1.3.1 Condition B12: System Operator – Transmission Owner Code

All Transmission Licensees are required to have the System Operator Transmission Owner Code ('STC') in place that defines the arrangements within the transmission sector and sets out how the transmission system operator can access and use transmission services provided by transmission owners.

The STC structure aligns with key activities within the transmission sector including:

- Planning Co-ordination (of transmission system development works and construction);
- Provision of transmission services within different operational timescales, and
- Payments from transmission system operator to providers of transmission services (after service has been delivered).

1.3.2 Condition B16: Electricity Network Innovation Strategy

All Transmission Licensees are required to have a joined-up approach to innovation and develop an Electricity Network Innovation Strategy that is reviewed every two years.

1.3.3 Condition D2: Obligation to provide transmission services

Each transmission owner is required to provide transmission services to the transmission system operator as defined in the STC. Transmission services provided to the transmission system operator include:

- enabling use to be made of existing transmission owner assets, and
- responding to requests for the construction of additional transmission system capacity (including system extension, disconnections and/or reinforcement).

1.3.4 Condition D3: Transmission system security standard and quality of service

Transmission owners are required to at all times plan, develop the transmission system in accordance with the National Electricity Transmission System Security and Quality of Supply Standard ('NETS SQSS').

A transmission owner with supporting evidence, may ask the Authority to grant derogation from the requirements set out in the NETS SQSS. Any decision in respect of NETS SQSS derogations are subject to the Authority's consideration of all relevant factors.

1.3.5 Condition D17: Whole Electricity System Obligations

Transmission owners are required to coordinate and cooperate with Transmission Licensees and electricity distributors in order to build common understanding of where actions taken by one could have cross-network impacts. A transmission owner should implement actions or processes that are identified that:

- will not have a negative impact on its network, and
- are in the interest of the efficient and economical operation of the total system.

Appendix B: Requirement for Development Consent Order

1.1 Electricity Network Infrastructure Developments

1.1.1 Developing the electricity transmission system in England and Wales subject to the type and scale of the project, may require one or more statutory consents which may include:

- planning permission under the Town and Country Planning Act 1990;
- a marine licence under the Marine and Coastal Access Act 2009;
- a Development Consent Order ("DCO") under the Planning Act 2008, and/or
- a variety of consents under related legislation.

1.1.2 The Planning Act 2008 defines developments of new electricity overhead lines of 132kV and above as Nationally Significant Infrastructure Projects ('NSIPs') requiring a DCO. Such an order may also incorporate Consent for other types of work that is associated with new overhead line infrastructure development, may be incorporated as part of a DCO that is granted.

1.1.3 Six National Policy Statements ("NPS") for energy infrastructure were designated by the Secretary of State for Energy and Climate Change in July 2011. The relevant NPSs for electricity transmission infrastructure developments are the Overarching National Policy Statement for Energy (EN-1) and the National Policy Statement for Electricity Networks Infrastructure (EN-5), which is read in conjunction with EN-1. In September 2021, Government consulted[18] on proposed updates to the NPS suite including EN-1 and EN-5. The proposed updates include clear linkages of EN-1 with policy objectives in respect of net-zero[19].

1.1.4 Section 104(3) of the Planning Act 2008 states that the decision maker must determine an application for a DCO in accordance with any relevant NPS, except in certain specified circumstances (such as where the adverse impact of the proposed development would outweigh its benefits). The energy NPSs therefore provide the primary policy basis for decisions on DCO applications for electricity transmission projects. The NPSs may also be a material consideration for decisions on other types of development consent in England and Wales (including offshore wind generation projects) and for planning applications under the Town and Country Planning Act 1990.

1.2 Demonstrating the Need for a Project

1.2.1 Part 3 of EN-1 sets out Government policy on the need for new nationally significant energy infrastructure projects. Paragraph 3.1 confirms that the UK needs all of the types of energy infrastructure covered by the NPS to achieve energy security and to

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[18] BEIS Consultation, Planning for new infrastructure: review of energy National Policy Statements, September 2021 https://www.gov.uk/government/consultations/planning-for-new-energy-infrastructure-review-of-energy-national-policy-statements

[19] Energy White Paper: Powering our net zero future, December 2020 https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future

dramatically reduce greenhouse gas emissions. It states that "substantial weight" should be given to the contribution which projects would make towards satisfying each need.

1.2.2 Description of the need for:

- new electricity transmission infrastructure is set out in EN-1 and EN-5
- new offshore/onshore wind generation is set out in EN-1 and EN-3, and
- new nuclear generation is set out in EN-1 and EN-6.

1.2.3 The need for new transmission infrastructure for this project is described in section 3 of this Report.

1.3 Assessment Principles Applied by Decision Maker

1.3.1 Part 4 of EN-1 sets out the general policies that are applied in determining DCO applications relating to new energy infrastructure. Paragraphs 2.3-2.5 of EN-5 set out the general assessment principles in the specific context of electricity networks infrastructure.

1.3.2 Principles of particular importance for transmission infrastructure projects include:

1.3.3 Presumption in Favour of Development

- Section 4.1 of EN-1 requires the Infrastructure Planning Commission (‘IPC’) to start with a presumption in favour of granting consent for energy NSIPs. This presumption applies unless any more specific and relevant policies set out in the relevant NPS clearly indicate that consent should be refused. The presumption is also subject to the exceptions set out in Section 104(2) of the Planning Act 2008.
- In assessing any application, the IPC should take account of potential:
  - benefits (e.g. the contribution to meeting the need for energy infrastructure, job creation and long term wider benefits), and
  - adverse impacts (e.g. long term and cumulative impacts but taking into account proposed mitigation measures.

1.3.4 Consideration of Alternatives

- Section 4.4 of EN-1 states that, from a planning policy perspective alone, there is no general requirement to consider alternatives or to establish whether the proposed project represents the best option. However, in relation to electricity transmission projects, paragraph 2.8.4 of EN-5 states that, "wherever the nature or proposed route of an overhead line proposal makes it likely that its visual impact will be particularly significant, the applicant should have given appropriate consideration to the potential costs and benefits of other feasible means of connection or reinforcement, including underground and subsea cables where appropriate."
- Section 4.4 of EN-1 also makes clear that there will be circumstances where an applicant is specifically required to include information in their application about the

main alternatives that were considered. These circumstances may include requirements under the Habitats Directive and the Birds Directive[20]

1.3.5 Adverse Impacts and Potential Benefits

- Part 5 of EN-1 covers the impacts that are common across all energy NSIPs and sections 2.6-2.9 of EN-5 consider impact in the specific context of electricity networks infrastructure.
- Those impacts identified in EN-1 include air quality and emissions, biodiversity and geological conservation, civil and military aviation and defence interests, coastal change (to the extent in or proximate to a coastal area), dust, odour, artificial light, smoke, steam and insect infestation, flood risk, historic environment, landscape and visual, land use, noise and vibration, socio-economic effects, traffic and transport, waste management and water quality and resources. The extent to which these impacts are relevant to a particular stage of a project, or are a relevant differentiator at a particular stage of the options appraisal process, will vary. In particular, some of these impacts are scoped out of this stage of the options appraisal process for this project. EN-5 considers specific potential impacts of electricity networks on biodiversity and geological conservation, landscape and visual, noise and vibration, and electric and magnetic fields.
- Potential impacts of particular importance for electricity transmission infrastructure projects include:

1.3.6 Good Design

- Section 4.5 of EN-1 stresses the importance of 'good design' for energy infrastructure, explaining that this goes beyond aesthetic considerations as fitness for purpose and sustainability are equally important. It is acknowledged in EN-1 that the nature of much energy infrastructure development will often limit the extent to which it can contribute to the enhancement of the quality of the area. Section 2.5 of EN-5 identifies a particular need for the applicant to demonstrate the principles of good design were applied in the proposed approach to mitigating the potential adverse impacts which can be associated with overhead lines.

1.3.7 Climate Change

- Section 4.8 of EN-1 explains how the effects of climate change should be taken into account and section 2.4 of EN-5 expands on this in the specific context of electricity networks infrastructure. DCO applications are required to set out the vulnerabilities / resilience of the proposals to flooding, effects of wind on overhead lines, higher average temperatures leading to increased transmission losses and earth movement or subsidence caused by flooding or drought (for underground cables).

1.3.8 Networks DCO Applications Submitted in Isolation

- Section 2.3 of EN-5 confirms that it can be appropriate for DCO applications for new transmission infrastructure to be submitted separately from applications for the generation that this infrastructure will serve. EN-5 explains that the need for the transmission project can be assessed on the basis of both contracted and reasonably anticipated generation.

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[20] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora; Council Directive 2009/147/EC on the conservation of wild birds.

1.3.9 Electricity Act Duties

- Paragraph 2.3.5 of EN-5 recognises developers' duties pursuant to section 9 of the Electricity Act to bring forward efficient and economical proposals in terms of network design, taking into account current and reasonably anticipated future generation demand, and its duty to facilitate competition and so provide a connection whenever and wherever one is required.

1.3.10 Adverse Impacts and Potential Benefits

- Part 5 of EN-1 covers the impacts that are common across all energy NSIPs and sections 2.6-2.9 of EN-5 consider impact in the specific context of electricity networks infrastructure.
- Those impacts identified in EN-1 include air quality and emissions, biodiversity and geological conservation, civil and military aviation and defence interests, coastal change (to the extent in or proximate to a coastal area), dust, odour, artificial light, smoke, steam and insect infestation, flood risk, historic environment, landscape and visual, land use, noise and vibration, socio-economic effects, traffic and transport, waste management and water quality and resources. The extent to which these impacts are relevant to a particular stage of a project, or are a relevant differentiator at a particular stage of the options appraisal process, will vary. In particular, some of these impacts are scoped out of this stage of the options appraisal process for this project. EN-5 considers specific potential impacts of electricity networks on biodiversity and geological conservation, landscape and visual, noise and vibration, and electric and magnetic fields.
- Potential impacts of particular importance for electricity transmission infrastructure projects include:
  - Landscape and Visual

    Paragraph 2.8.2 of EN-5 states that the Government does not believe that development of overhead lines is generally incompatible in principle with the developer statutory duty under section 9 of the Electricity Act 1989 to have regard to amenity and to mitigate impacts. However, EN-5 recognises that in practice overhead lines can give rise to adverse landscape and visual impacts, dependent upon their scale, siting, degree of screening and the nature of the landscape and local environment through which they are routed.

    In relation to alternative technologies for electricity transmission projects, paragraph 2.8.9 of EN-5 states that, "each project should be assessed individually on the basis of its specific circumstances and taking account of the fact that Government has not laid down any general rule about when an overhead line should be considered unacceptable. The IPC should, however, only refuse consent for overhead line proposals in favour of an underground or subsea line if it is satisfied that the benefits from the non-overhead line alternative will clearly outweigh any extra economic, social and environmental impacts and the technical difficulties are surmountable." Paragraph 2.8.7 of EN-5 endorses the Holford Rules which are a set of "common sense" guidelines for routeing new overhead lines.

Appendix C: Technology Overview

1.1.1 This section provides an overview of the technologies available when the strategic options described in this Report were identified. It provides a high-level description of the relevant features of each technology. The costs for each technology are presented in 0.

1.1.2 The majority of electricity systems throughout the world are AC systems. Consumers have their electricity supplied at different voltages depending upon the amount of power they consume e.g. 230V for domestic customers and 11 kV for large factories and hospitals. The voltage level is relatively easy to change when using AC electricity, which means a more economical electricity network can be developed for customer requirement. This has meant that the electrification of whole countries could be and was delivered quickly and efficiently using AC technology.

1.1.3 DC electricity did not develop as the means of transmitting large amounts of power from generating stations to customers because DC is difficult to transform to a higher voltage and bulk transmission by low voltage DC is only effective for transporting power over short distances. However, DC is appropriate in certain applications such as the extension of an existing AC system or when providing a connection to the transmission system.

1.1.4 In terms of voltage, the transmission system in England and Wales operates at both 275 kV and 400 kV. The majority of National Grid's transmission system is now constructed and operated at 400 kV, which facilitates higher power transfers and lower transmission losses.

1.1.5 There are a number of different technologies that can be used to provide transmission connections. These technologies have different features which affect how, when and where they can be used. The main technology options for electricity transmission are:

- Overhead lines
- Underground cables
- Gas Insulated Lines ("GIL"), and
- High Voltage Direct Current (HVDC).

1.1.6 This appendix provides generic information about each of these four technologies. Further information, including a more detailed technical review is available in a series of factsheets that can be found at the project website referenced at the beginning of this Report.

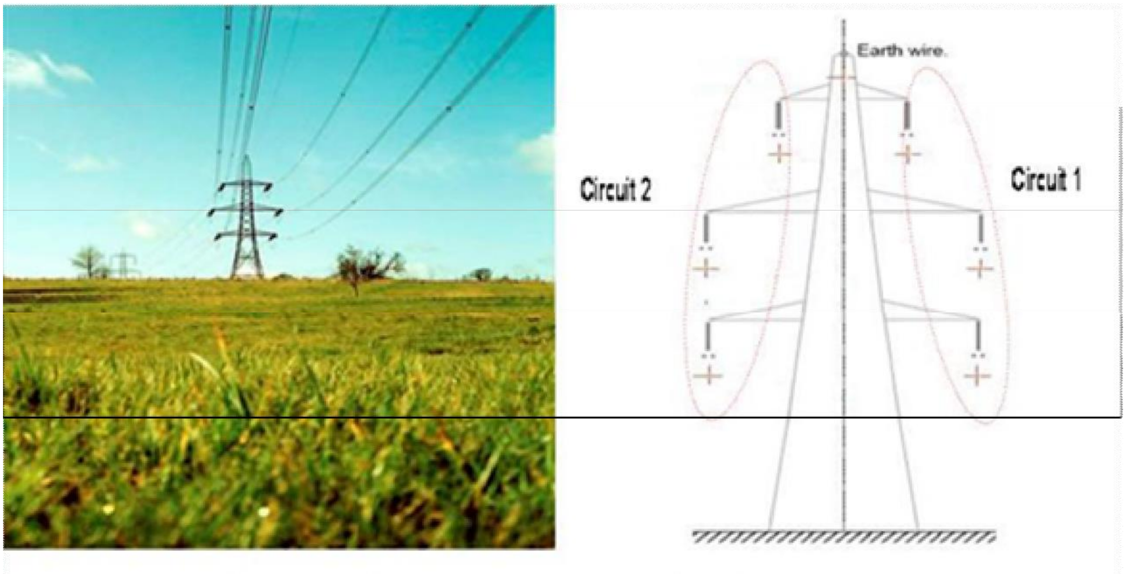
1.2 Overhead lines

1.2.1 Overhead lines form the majority of the existing transmission system circuits in Great Britain and in transmission systems across the world. As such there is established understanding of their construction and use.

1.2.2 Overhead lines are made up of three main component parts which are; conductors (used to transport the power), pylons (used to support the conductors) and insulators (used to safely connect the conductors to pylons).

1.2.3 Figure C.1 shows a typical pylon used to support two 275 kV or 400 kV overhead line circuits. This type of pylon has six arms (three either side), each carrying a set (or bundle) of conductors.

Figure C.1: Example of a 400 kV Double-circuit Tower



1.2.4 The number of conductors supported by each arm depends on the amount of power to be transmitted and will be either two, three or four conductors per arm. Technology developments have increased the capacity that can be carried by a single conductor and therefore, new overhead lines tend to have two or three conductors per arm.

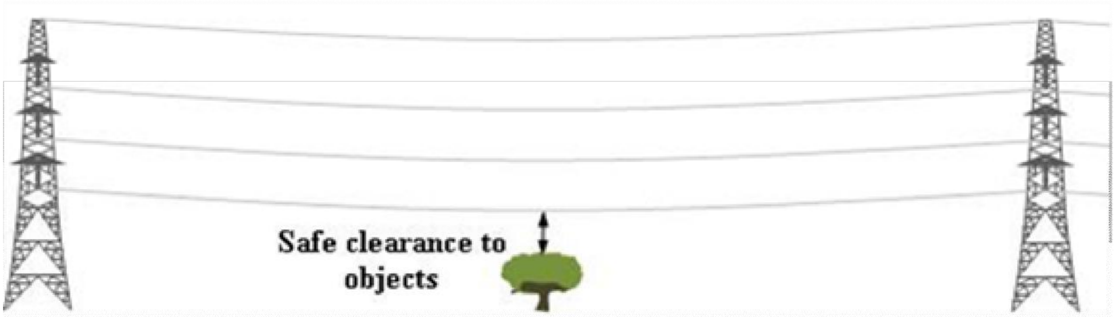
1.2.5 With the conclusion of the Royal Institute of British Architects (RIBA) pylon design competition[21] and other recent work with manufacturers to develop alternative pylon designs, National Grid is now able to consider a broader range of pylon types, including steel lattice and monopole designs. The height and width is different for each pylon type, which may help National Grid to manage the impact on landscape and visual amenity better. Figure C.2, below, shows an image on the monopole design called the T-pylon that was developed by National Grid.

[21] Pylon Design an RIBA competition, https://www.architecture.com/awards-and-competitions-landing-page/competitions-landing-page/pylon

Figure C.2: The T-pylon

1.2.6 Pylons are designed with sufficient height to ensure that the clearances between each conductor and between the lowest conductor and the ground, buildings or structures are adequate to prevent electricity jumping across. The minimum clearance between the lowest conductor and the ground is normally at the mid-point between pylons. There must be sufficient clearance between objects and the lowest point of the conductor as shown in Figure C.3.

Figure C.3: Safe height between lowest point of conductor and other obstacle ("Safe Clearance")



1.2.7 The distance between adjacent pylons is termed the 'span length'. The span length is governed by a number of factors, the principal ones being pylon height, number and size of conductors (i.e. weight), ground contours and changes in route direction. A balance must therefore be struck between the size and physical presence of each tower versus the number of towers; this is a decision based on both visual and economic aspects. The typical 'standard' span length used by National Grid is approximately 360m.

1.2.8 Lower voltages need less clearance and therefore the pylons needed to support 132 kV lines are not as high as traditional 400 kV and 275 kV pylons. However, lower voltage circuits are unable to transport the same levels of power as higher voltage circuits.

1.2.9 National Grid has established operational processes and procedures for the design, construction, operation and maintenance of overhead lines. Circuits must be taken out of service from time to time for repair and maintenance. However, shorter emergency restoration times are achievable on overhead lines as compared, for example, to underground cables. This provides additional operational flexibility if circuits need to be rapidly returned to service to maintain a secure supply of electricity when, for example, another transmission circuit is taken out of service unexpectedly.

1.2.10 In addition, emergency pylons can be erected in relatively short timescales to bypass damaged sections and restore supplies. Overhead line maintenance and repair therefore does not significantly reduce security of supply risks to end consumers.

1.2.11 Each of the three main components that make up an overhead line has a different design life, which are:

- Between 40 and 50 years for overhead line conductors
- 80 years for pylons
- Between 20 and 40 years for insulators.

1.2.12 National Grid expects an initial design life of around 40 years, based on the specified design life of the component parts. However, pylons can be easily refurbished and so substantial pylon replacement works are not normally required at the end of the 40 year design life.

1.3 Underground Cables

1.3.1 Underground cables at 275 kV and 400 kV make up approximately 10% of the existing transmission system in England and Wales, which is typical of the proportion of underground to overhead equipment in transmission systems worldwide. Most of the underground cable is installed in urban areas where achieving an overhead route is not feasible. Examples of other situations where underground cables have been installed, in preference to overhead lines, include crossing rivers, passing close to or through parts of nationally designated landscape areas and preserving important views.

1.3.2 Underground cable systems are made up of two main components – the cable and connectors. Connectors can be cable joints, which connect a cable to another cable, or overhead line connectors in a substation.

1.3.3 Cables consist of an electrical conductor in the centre, which is usually copper or aluminium, surrounded by insulating material and sheaths of protective metal and plastic. The insulating material ensures that although the conductor is operating at a high voltage, the outside of the cable is at zero volts (and therefore safe). Figure C.4 shows a cross section of a transmission cable and a joint that is used to connect two underground cables.

Figure C.4: Cable Cross-Section and Joint

1.3.4 Underground cables can be connected to above-ground electrical equipment at a substation, enclosed within a fenced compound. The connection point is referred to as a cable sealing end. Figure C.5 shows two examples of cable sealing end compounds.

Figure C.5: Cable Sealing End Compounds

1.3.5 An electrical characteristic of a cable system is capacitance between the conductor and earth. Capacitance causes a continuous 'charging current' to flow, the magnitude of which is dependent on the length of the cable circuit (the longer the cable, the greater the charging current) and the operating voltage (the higher the voltage the greater the current). Charging currents have the effect of reducing the power transfer through the cable.

1.3.6 High cable capacitance also has the effect of increasing the voltage along the length of the circuit, reaching a peak at the remote end of the cable.

1.3.7 National Grid can reduce cable capacitance problems by connecting reactive compensation equipment to the cable, either at the ends of the cable, or, in the case of longer cables, at regular intervals along the route. Specific operational arrangements and switching facilities at points along the cable circuit may also be needed to manage charging currents.

1.3.8 Identifying faults in underground cable circuits often requires multiple excavations to locate the fault and some repairs require removal and installation of new cables, which can take a number of weeks to complete.

1.3.9 High voltage underground cables must be regularly taken out of service for maintenance and inspection and, should any faults be found and depending on whether cable excavation is required, emergency restoration for security of supply reasons typically takes a lot longer than for overhead lines (days rather than hours).

1.3.10 The installation of underground cables requires significant civil engineering works. These make the construction times for cables longer than overhead lines.

1.3.11 The construction swathe required for two AC circuits comprising two cables per phase will be between 35-50 m wide.

1.3.12 Each of the two main components that make up an underground cable system has a design life of between 40 and 50 years.

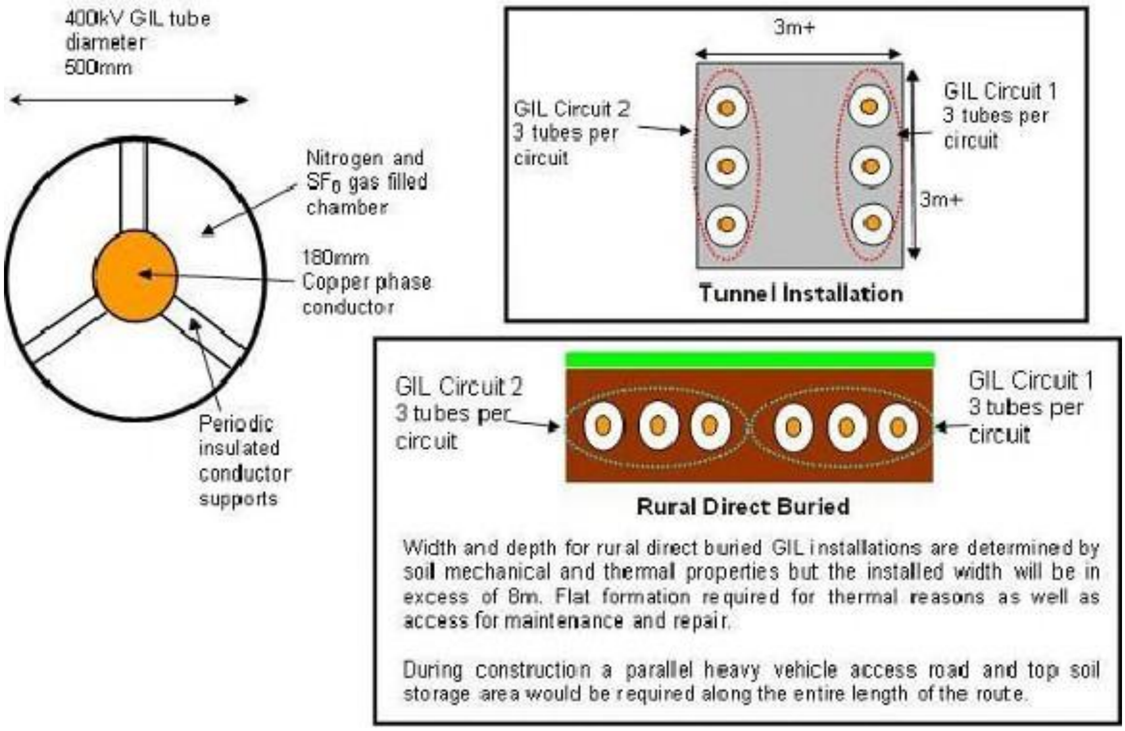
1.3.13 Asset replacement is generally expected at the end of design life. However, National Grid’s asset replacement decisions (that are made at the end of design life) will also take account of actual asset condition and may lead to actual life being longer than the design life.

1.4 Gas Insulated Lines (“GIL”)

1.4.1 GIL is an alternative to underground cable for high voltage transmission. GIL has been developed from the well-established technology of gas-insulated switchgear, which has been installed on the transmission system since the 1960s.

1.4.2 GIL uses a mixture of nitrogen and sulphur hexafluoride (SF6) gas to provide the electrical insulation. GIL is constructed from welded or flanged metal tubes with an aluminium conductor in the centre. Three tubes are required per circuit, one tube for each phase. Six tubes are therefore required for two circuits, as illustrated in Figure C.6 below.

Figure C.6: Key Components of GIL



1.4.3 GIL tubes are brought to site in 10 – 20 m lengths and they are joined in situ. It is important that no impurities enter the tubes during construction as impurities can cause the gas insulation to fail. GIL installation methods are therefore more onerous than those used in, for example, natural gas pipeline installations.

1.4.4 A major advantage of GIL compared to underground cable is that it does not require reactive compensation.

1.4.5 The installation widths over the land can also be narrower than cable installations, especially where more than one cable per phase is required.

1.4.6 GIL can have a reliability advantage over cable in that it can be re-energised immediately after a fault (similar to overhead lines) whereas a cable requires investigations prior to re-energisation. If the fault was a transient fault it will remain energised and if the fault was permanent the circuit will automatically and safely de-energise again.

1.4.7 There are environmental concerns with GIL as the SF_6[22] gas used in the insulating gas mixture is a potent 'greenhouse gas'. Since SF6 is an essential part of the gas mixture GIL installations are designed to ensure that the risk of gas leakage is minimised.

1.4.8 There are a number of ways in which the risk of gas leakage from GIL can be managed, which include:

- use of high-integrity welded joints to connect sections of tube;
- designing the GIL tube to withstand an internal fault; and

[22] SF_6 is a greenhouse gas with a global warming potential, according to the Intergovernmental Panel on Climate Change, Working Group 1 (Climate Change 2007, Chapter 2.10.2), of 22,800 times that of CO2. www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

- splitting each GIL tube into a number of smaller, discrete gas zones that can be independently monitored and controlled.

1.4.9 At decommissioning the SF_6 can be separated out from the gas mixture and either recycled or disposed of without any environmental damage.

1.4.10 GIL is a relatively new technology and therefore has limited historical data, meaning that its operational performance has not been empirically proven. National Grid has two GIL installations on the transmission system which are 545 m and 150 m long[23]. These are both in electricity substations; one is above ground and the other is in a trough. The longest directly buried transmission voltage GIL in the world is approximately one kilometre long and was recently installed on the German transmission system around Frankfurt Airport.

1.4.11 In the absence of proven design life information, and to promote consistency with assessment of other technology options, National Grid assesses GIL over a design life of up to 40 years.

1.5 High Voltage Direct Current ("HVDC")

1.5.1 HVDC technology can provide efficient solutions for the bulk transmission of electricity between AC electricity systems (or between points on an electricity system).

1.5.2 There are circumstances where HVDC has advantages over AC, generally where transmission takes place over very long distances or between different, electrically-separate systems, such as between Great Britain and countries in Europe such as France, Belgium, The Netherlands, Ireland etc.…

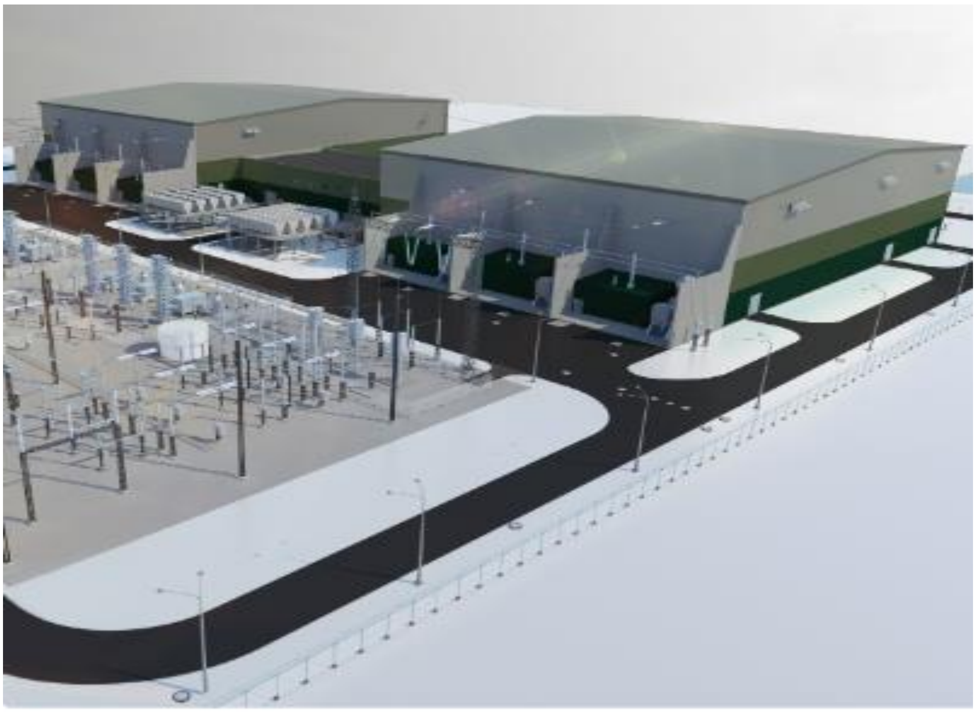
1.5.3 HVDC links may also be used to connect a generating station that is distant from the rest of the electricity system. For example, very remote hydro-electric schemes in China are connected by HVDC technology with overhead lines.

1.5.4 Proposed offshore wind farms to be located over 60 km from the coast of Great Britain are likely to be connected using HVDC technology as an alternative to an AC subsea cable. This is because AC subsea cables over 60 km long have a number of technical limitations, such as high charging currents and the need for mid-point compensation equipment.

1.5.5 The connection point between AC and DC electrical systems has equipment that can convert AC to DC (and vice versa), known as a converter. The DC electricity is transmitted at high voltage between converter stations. Convertor stations can use two types of technology. "Classic" or Current Source Convertors (CSC) were the first type of HVDC technology developed and this design was used for National Grid's Western Link. Voltage Source Convertors (VSC) are a newer design and offer advantages over the previous CSC convertors, as they can better support weaker systems and offer more flexibility in the way they operate, including direction of power flow.

[23] The distances are based on initial manufacturer estimates of tunnel and buried GIL dimensions which would be subject to full technical appraisal by National Grid and manufacturers to achieve required ratings which may increase the separation required. It should be noted that the diagram does not show the swathe of land required during construction. Any GIL tunnel installations would have to meet the detailed design requirements of National Grid for such installations.

Figure C.7: VSC convertor Station



1.5.6 HVDC can offer advantages over AC underground cable, such as:

- a minimum of two cables per circuit is required for HVDC whereas a minimum of three cables per circuit is required for AC.
- reactive compensation mid-route is not required for HVDC.
- cables with smaller cross sectional areas can be used (compared to equivalent AC system rating).
- This allows HVDC cables to be more easily installed for subsea applications than AC cables for a given capacity.

1.5.7 HVDC cables are generally based upon two technology types Mass Impregnated and Extruded technologies. VSC technology may utilise either technology type, whereas CSC technology tends to be limited to Mass Impregnated cables due to the way poles are reversed for change of power flow direction.

Figure C.8: HVDC Cable Laying Barge at transition between shore and sea cables

1.5.8 HVDC systems have a design life of about 40 years. This design life period is on the basis that large parts of the converter stations (valves and control systems) would be replaced after 20 years.

Appendix D: Economic Appraisal

1.1.1 As part of the economic appraisal of Strategic Options, National Grid makes comparative assessments of the lifetime costs associated with each technology option that is considered to be feasible.

1.1.2 This section provides an overview of the methods that National Grid uses to estimate lifetime costs as part the economic appraisal of a Strategic Option. It also provides a summary of generic capital cost information for transmission system circuits for each technology option included in 0 and an overview of the method that National Grid uses to assess the Net Present Value (“NPV”) of costs that are expected to be incurred during the lifetime of new transmission assets.

1.1.3 The IET, PB/CCI Report[24] presents cost information in size of transmission circuit capacity categories for each circuit design that was considered as part of the independent study. To aid comparison between the cost data presented in the IET PB/CCI Report and that used by National Grid for appraisal of Strategic Options, this appendix includes cost estimates using National Grid cost data for circuit designs that are equivalent to those considered as part of the independent study. Examples in this Appendix are presented using the category size labels of “Lo”, “Med” and “Hi” used in the IET PB/CCI Report.

1.2 Lifetime Costs for Transmission

1.2.1 For each technology option appraised within a Strategic Option, National Grid estimates total lifetime costs for the new transmission assets. The total lifetime cost estimate consists of the sum of the estimates of the:

- initial capital cost of developing, procuring, installing and commissioning the new transmission assets, and
- net present value (“NPV”) of costs that are expected to be incurred during the lifetime of these new transmission assets

1.3 Capital Cost Estimates

1.3.1 At the initial appraisal stage, National Grid prepares indicative estimates of the capital costs. These indicative estimates are based on the high-level scope of works defined for each Strategic Option in respect of each technology option that is considered to be feasible. As these estimates are prepared before detailed design work has been carried out, National Grid takes account of equivalent assumptions for each option. Final project costs for any solution taken forward following detailed design and risk mitigation will be in excess of any high-level appraisal cost. However, all options would incur these increases in the development of a detailed solution.

[24] “Electricity Transmission Costing Study – An Independent Report Endorsed by the Institution of Engineering & Technology” by Parsons Brinckerhoff in association with Cable Consulting International. Page 10 refers to Double circuit capacities. http://www.theiet.org/factfiles/transmission-report.cfm

1.3.2 This section considers the capital costs in two parts, firstly the AC technology costs are discussed, followed by HVDC technologies. Each of these technologies is described in 0 in more detail.

1.4 AC Technology Capital Cost Estimates

1.4.1 Table D.1 shows the category sizes that are relevant for AC technology circuit designs:

Table D.1 – AC Technology Circuit Designs

Category	Design	Rating
Lo	Two AC circuits of 1,595 MVA	3,190 MVA
Med	Two AC circuits of 3,190 MVA	6,380 MVA
Hi	Two AC circuits of 3,465 MVA	6,930 MVA

Table D.2 provides a summary of technology configuration and capital cost information (in financial year 2020/21 prices) for each of the AC technology options that National Grid considers as part of an appraisal of Strategic Options.

Table D.2 - AC Technology Configuration and National Grid Capital Costs by Rating

IET, PB/CCI Report short-form label	Circuit Ratings by Voltage		Technology Configuration			Capital Costs		
	275kV AC Technologies	400kV AC Technologies	Overhead Line (OHL)	AC Underground Cable (AC Cable)	Gas Insulated Line (GIL)	Overhead Line (OHL)	AC Underground Cable (AC Cable)	Gas Insulated Line (GIL)
	Total rating for two Circuits (2 x rating of each circuit)	Total rating for two Circuits (2 x rating of each circuit)	No. of Conductors Sets "bundles" on each arm/circuit of a pylon	No. of Cables per phase	No of direct buried GIL tubes per phase	Cost for a "double" two circuit pylon route (Cost per circuit, of a double circuit pylon route)	Cost for a two circuit AC cable route (Cost per circuit, of a two circuit AC cable route)	Cost for a two circuit GIL route (Cost per circuit, of a two circuit GIL route)
Lo	3190MVA (2 x 1595MVA) [2000MVA 2 x 1000MVA for AC Cable only]	3190MVA (2 x 1595MVA)	2 conductor sets per circuit (6 conductors per circuit)	1 Cable per Phase (3 cables per circuit)	1 tube per phase (3 standard GIL tubes per circuit)	£3.31m/km (£1.66m/km)	£16.35m/km (£8.17m/km)	£26.81m/km (£13.411m/km)
Med	N/A [3190MVA 2 x 1595MVA for AC Cable only]	6380MVA (2 x 3190MVA)	2 conductor sets per circuit (6 conductors per circuit)	2 Cables per Phase (6 cables per circuit)	1 tube per phase (3 "developing" new large GIL tubes per circuit)	£3.64m/km (£1.82m/km)	£28.32m/km (£14.16m/km)	£31.13m/km (£15.56m/km)

Hi	N/A	6930MVA (2 x 3465MVA)	3 conductor sets per circuit (9 conductors per circuit)	3 Cables per Phase (9 cables per circuit)	2 tubes per phase (6 standard GIL tubes per circuit)	£3.98m/km (£1.99m/km)	£39.89m/km (£19.95m/km)	£43.25m/km (£21.63m/km)

Notes: -

1. Capital Costs for all technologies are based upon rural/arable land installation with no major obstacles (examples of major obstacles would be Roads, Rivers, Railways etc…)
2. All underground AC Cable and GIL technology costs are for direct buried installations only. AC cable and GIL Tunnel installations would have a higher capital installation cost than direct buried rural installations. However, AC cable or GIL replacement costs following the end of conductor life would benefit from re-use of the tunnel infrastructure.
3. AC cable installation costs exclude the cost of reactors and mid point switching stations, which are described later in this appendix.
4. 275kV circuits will often require Super-Grid Transformers (SGT) to allow connection into the 400kV system, SGT capital costs are not included above but described later in this appendix.
5. 275kV AC cable installations above 1000MVA, as indicated in the table above, would require 2 cables per phase to be installed to achieve ratings of 1595MVA per circuit at 275kV.

1.4.2 Table D.2 provides a summary of the capital costs associated with the key[25] components of transmission circuits for each technology option. Additional equipment is required for technology configurations that include new:

- AC underground cable circuits
- Connections between 400 kV and 275 kV parts of the National Grid's transmission system.

1.4.3 The following sections provide an overview of the additional requirements associated with each of these technology options and indicative capital costs of additional equipment.

1.5 AC Underground Cable additional equipment

1.5.1 0 of this Report provides a summary of the electrical characteristics of AC underground cable systems and explains that reactive gain occurs on AC underground cables.

1.5.2 Table D.3 provides a summary of the typical reactive gain within AC underground cable circuits forming part of the National Grid's transmission system.

Table D.3 – Reactive Gain Within AC underground cable circuits

Category	Voltage	Design	Reactive Gain per circuit
Lo	275 kV	One 2500 mm^2 cable per phase	5 Mvar/km
Med	275 kV	Two 2500 mm^2 cable per phase	10 Mvar/km
Lo	400 kV	One 2500 mm^2 cable per phase	10 Mvar/km
Med	400 kV	Two 2500 mm^2 cable per phase	20 Mvar/km
Hi	400 kV	Three 2500 mm^2 cable per phase	30 Mvar/km

1.5.3 National Grid is required to ensure that reactive gain on any circuit that forms part of its transmission system does not exceed 225 Mvar. Above this limit, reactive gain would lead to unacceptable voltages (voltage requirements as defined in the NETS SQSS). In order to manage reactive gain and therefore voltages, reactors are installed on AC underground cable circuits to ensure that reactive gain in total is less than 225 Mvar.

1.5.4 For example a 50 km "Med" double circuit would have an overall reactive gain of 1000 Mvar per circuit (2000 Mvar in total for two circuits). The standard shunt reactor size installed at 400 kV on the National Grid transmission system is 200 Mvar. Therefore four 200 Mvar reactors (800 Mvar) need to be installed on each circuit or eight 200 Mvar

[25] Components that are not required for all technology options are presented separately in this Appendix.

reactors (1600 Mvar) reactors for the two circuits. Each of these reactors cost £8.7m adding £69.6m to an overall cable cost for the example double circuit above.

1.5.5 Mid point switching stations may be required as part of a design to meet the reactive compensation requirements for AC underground cable circuit. The need for switching stations is dependent upon cable design, location and requirements which cannot be fully defined without detailed design.

1.5.6 For the purposes of economic appraisal of Strategic Options, National Grid includes a cost allowance that reflects typical requirements for switching stations. These allowances shown in Table D.4 are:

Table D.4 – Reactive Gain Within AC underground cable circuits

Category	Switching Station Requirement
Lo	Reactive Switching Station every 60km between substations
Med	Reactive Switching Station every 30km between substations
Hi	Reactive Switching Station every 20km between substations

1.5.7 It is noted that more detailed design of AC underground cable systems may require a switching station after a shorter or longer distance than the typical values used by National Grid at the initial appraisal stage.

1.5.8 Table D.5 below shows the capital cost associated with AC underground cable additional equipment.

Table D.5 – Additional costs associated with AC underground cables

Category	Cost per mid point switching station	Cost per 200 Mvar reactor
Lo	£15.09m	£8.7m per reactor
Med	£18.44m	
Hi	£18.44m	

1.6 Connections between AC 275 kV and 400 kV circuits additional equipment

1.6.1 Equipment that transform voltages between 275kV and 400kV (a 400/275 kV supergrid transformer or “SGT”) is required for any new 275 kV circuit that connects to a 400 kV part of the National Grid’s transmission system (and vice versa). The number of supergrid transformers needed is dependent on the capacity of the new circuit. National Grid can estimate the number of SGTs required as part of an indicative scope of works that is used for the initial appraisal of Strategic Options.

1.6.2 Table D.6 below shows the capital cost associated with the SGT requirements.

Table D.6 – Additional costs associated with 275kV circuits requiring connection to the 400kV system

275kV Equipment	Capital Cost (SGT - including civil engineering work)
400/275kV SGT 1100MVA (excluding switchgear)	£7.75m per SGT

1.7 High Voltage Direct Current ("HVDC") Capital Cost Estimates

1.7.1 Conventional HVDC technology sizes are not easily translated into the "Lo", "Med" and "Hi" ratings suggested in the IET, PB/CCI report. Whilst National Grid information for HVDC is presented for each of these categories, there are differences in the circuit capacity levels. As part of an initial appraisal, National Grid's assessment is based on a standard 2GW converter size. Higher ratings are achievable using multiple circuits.

1.7.2 The capital costs of HVDC installations can be much higher than for equivalent AC overhead line transmission routes. Each individual HVDC link, between each converter station, requires its own dedicated set of HVDC cables. HVDC may be more economic than equivalent AC overhead lines where the route length is many hundreds of kilometres.

1.7.3 Table D.7 provides a summary of technology configuration and capital cost information (in financial year 2020/21 prices) for each of the HVDC technology options that National Grid considers as part of an appraisal of Strategic Options.

Table D.7 - HVDC Technology Capital Costs for 2GW installations

HVDC Converter Type	2 GW Total HVDC Link Converter Costs (Converter Cost at Each End)	2GW DC Cable Pair Cost
Current Source Technology or "Classic" HVDC	£475m HVDC link cost (£237.5m at each end)	£3.09m/km VDC
Voltage Source Technology HVDC	£534.38m HVDC link cost (£267.19m at each end)	£3.09m/km

Notes:

- Sometimes a different HVDC capacity (different from the required AC capacity) can be utilised for a project due to the different way HVDC technology can control power flow. The capacity requirements for HVDC circuits will be specified in any option considering HVDC. The cost shall be based upon Table C.4 above.
- Where a single HVDC Link is proposed as an option, to maintain compliance with the NETS SQSS, there may be a requirement to install an additional "Earth Return" DC cable. For example a 2GW Link must be capable of operating at ½ its capacity i.e. 1GW during maintenance or following a cable fault. To allow this operation the additional cable known as an "Earth Return" must be installed, this increases cable costs by a further 50% to £4.6m/km.

- Capital Costs for HVDC cable installations are based upon subsea or rural/arable land installation with no major obstacles (examples of major obstacles would be Subsea Pipelines, Roads, Rivers, Railways etc…)

1.7.4 Costs can be adjusted from this table to achieve equivalent circuit ratings where required. For example a "Lo" rating 3190 MW would require two HVDC links of (1.6 GW capacity each), while "Med" and "Hi" rating 6380 MW-6930 MW would require three links with technology stretch of (2.1-2.3 GW each).

1.7.5 Converter costs at each end can also be adjusted, by Linear scaling, from the cost information in Table D.7, to reflect the size of the HVDC link being appraised. HVDC Cable costs are normally left unaltered, as operating at the higher load does not have a large impact the cable costs per km.

1.7.6 The capacity of HVDC circuits assessed for this Report is not always exactly equivalent to capacity of AC circuits assessed. However, Table D.8 below illustrates how comparisons may be drawn using scaling methodology outlined above.

Table D.8 – Illustrative example using scaled 2GW HVDC costs to match equivalent AC ratings (only required where HVDC requirements match AC technology circuit capacity requirements)

IET, PB/CCI Report short-form label	**Converter Requirements (Circuit Rating)**	**Total Cable Costs/km (Cable Cost per link)**	**CSC "Classic" HVDC Total Converter Capital Cost (Total Converter cost per end)**	**VSC HVDC Total Converter Capital Cost (Total Converter cost per end)**
Lo	2 x 1.6 GW HVDC Links (3190MW)	£5.82m/km (2 x £2.91/km)	£704m (4 x £176m [4 converters 2 each end])	(4 x £736m (4 x £184m [4 converters 2 each end])
Med	3 x 2.1* GW HVDC Links (6380MW)	£9.27m/km (3 x £3.09/km)	£1422m (6 x £237m [6 converters 3 each end])	£1602m (6 x £267m [6 converters 3 each end])
Hi	3 x 2.3* GW HVDC Links (6930MW)	£10.32m/km (3 x £3.44/km)	£1818m (6 x £303m [6 converters 3 each end])	£1890m (6 x £315m [6 converter 3 each end])

Notes:

- Costs based on 2GW costs shown in Table C.4 and table shows how HVDC costs are estimated based upon HVDC capacity required for each option.
- Scaling can be used to estimate costs for any size of HVDC link required.
- *Current subsea cable technology for VSC design restricted to 2GW, so above examples illustrative if technology should become available.

1.8 Indication of Technology end of design life replacement impact

1.8.1 It is unusual for a part of National Grid's transmission system to be decommissioned and the site reinstated. In general, assets will be replaced towards the end of the assets design life. Typically, transmission assets will be decommissioned and removed only as part of an upgrade or replacement by different assets.

1.8.2 National Grid does not take account of replacement costs in the lifetime cost assessment.

1.8.3 National Grid's asset replacement decisions take account of actual asset condition. This may lead to actual life of any technology being longer or shorter than the design life, depending on the environment it is installed in, lifetime loading, equipment family failures among other factors for example.

1.8.4 The following provides a high level summary of common replacement requirements applicable to specific technology options:

- OHL - Based on the design life of component parts, National Grid assumes an initial design life of around 40 years for overhead line circuits. After the initial 40 year life of an overhead line circuit, substantial pylon replacement works would not normally be required. The cost of Pylons is reflected in the initial indicative capital costs, but the cost of replacement at 40 years would not include the pylon cost. As pylons have an 80 year life and can be re-used to carry new replacement conductors. The replacement costs for overhead line circuits at the end of their initial design life are assessed by National Grid as being around 50% of the initial capital cost, through the re-use of pylons.
- AC underground Cable - At the end of their initial design life, circa 40 years, replacement costs for underground cables are estimated to be equal or potentially slightly greater than the initial capital cost. This is because of works being required to excavate and remove old cables prior to installing new cables in their place in some instances.
- GIL - At the end of the initial design life, circa 40 years, estimated replacement costs for underground GIL would be equal to or potentially greater than the initial capital cost. This is because of works being required to excavate and remove GIL prior to installing new GIL in their place in some instances.
- HVDC - It should be noted at the end of the initial design life, circa 40 years, replacement costs for HVDC are significant. This due to the large capital costs for the replacement of converter stations and the cost of replacing underground or subsea DC cables when required.

1.9 Net Present Value Cost Estimates

1.9.1 At the initial appraisal stage, National Grid prepares estimates of the costs that are expected to be incurred during the design lifetime of the new assets. National Grid considers costs associated with:

- Operation and maintenance
- Electrical losses

1.9.2 For both categories, Net Present Value ("NPV") calculations are carried out using annual cost estimates and a generic percentage discount rate over the design life period associated with the technology option being considered.

1.9.3 The design life for all technology equipment is outlined in the technology description in 0. The majority of expected design lives are of the order of 40 years, which is used to assess the following NPV cost estimates below.

1.9.4 In general discount rates used in NPV calculations would be expected to reflect the normal rate of return for the investor. National Grid's current rate of return is 6.25%. However, the Treasury Green Book recommends a rate of 3.5% for the reasons set out below[26]

"The discount rate is used to convert all costs and benefits to 'present values', so that they can be compared. The recommended discount rate is 3.5%. Calculating the present value of the differences between the streams of costs and benefits provides the net present value (NPV) of an option. The NPV is the primary criterion for deciding whether government action can be justified."

1.9.5 National Grid considered the impact of using the lower Rate of Return (used by UK Government) on lifetime cost of losses assessments for transmission system investment proposals. Using the rate of 3.5% will discount loss costs, at a lower rate than that of 6.25%. This has the overall effect of increasing the 40 year cost of losses giving a more onerous cost of losses for higher loss technologies.

1.9.6 For the appraisal of Strategic Options, National Grid recognises the value of closer alignment of its NPV calculations with the approach set out by government for critical infrastructure projects.

1.10 Annual Operations and Maintenance Cost

1.10.1 The maintenance costs associated with each technology vary significantly depending upon type. Some electrical equipment is maintained regularly to ensure system performance is maintained. More complex equipment like HVDC converters have a significantly higher cost associated with them, due to their high maintenance requirements for replacement parts. Table D.9 shows the cost of maintenance for each technology, which unlike capital and losses is not dependent on capacity.

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[26] http://www.hm-treasury.gov.uk/d/green_book_complete.pdf Paragraph 5.49 on Page 26 recommends a discount rate of 3.5% calculation for NPV is also shown in the foot note of this page.

NPV calculations are carried out using the following equation over the period of consideration.

Dn =1/(1 + r)n

Where Dn = Annual Loss Cost, r = 3.5% and n = 40 years

Table D.9 – Annual maintenance costs by Technology

	Overhead Line (OHL)	**AC Underground Cable (AC Cable)**	**Gas Insulated Line (GIL)**	**High Voltage Direct Current (HVDC)**
Circuit Annual maintenance cost per two circuit km (AC) (Annual cost per circuit Km [AC])	£2,660/km (£1,330/km)	£5,644.45/km (£2,822.22/km)	£2,687.83/km (£1,343.92/km)	£134/km Subsea Cables
Associated equipment Annual Maintenance cost per item	N/A	£6,719.58 per reactor £41,661 per switching station	N/A	£1,300,911 per converter station
Additional costs for 275 kV circuits requiring connection to the 400kV system				
275/400 kV SGT 1100 MVA Annual maintenance cost per SGT	£6,719.58 per SGT	£6,719.58 per SGT	£6.719.58 per SGT	N/A

1.11 Annual Electrical Losses and Cost

1.11.1 At a system level annual losses on the National Grid electricity system equate to less the 2% of energy transported. This means that over 98% of the energy entering the transmission system from generators/interconnectors reaches the bulk demand substations where the energy transitions to the distribution system. Electricity transmission voltages are used to reduce losses, as more power can be transported with lower currents at transmission level, giving rise to the very efficient loss level achieved of less than 2%. The calculations below are used to show how this translates to a transmission route.

1.11.2 Transmission losses occur in all electrical equipment and are related to the operation and design of the equipment. The main losses within a transmission system come from heating losses associated with the resistance of the electrical circuits, often referred to as I2R losses (the electrical current flowing through the circuit, squared, multiplied by the resistance). As the load (the amount of power each circuit is carrying) increases, the current in the circuit is larger.

1.11.3 The average load of a transmission circuit which is incorporated into the transmission system is estimated to be 34% (known as a circuit average utilisation). This figure is calculated from the analysis of the load on each circuit forming part of National Grid's transmission system over the course of a year. This takes account of varying generation and demand conditions and is an appropriate assumption for the majority of Strategic Options.

1.11.4 This level of circuit utilisation is required because if a fault occurs there needs to be an alternative route to carry power to prevent wide scale loss of electricity for homes, business, towns and cities. Such events would represent a very small part of a circuit's 40 year life, but this availability of alternative routes is an essential requirement at all times to provide secure electricity supplies to the nation.

1.11.5 In all AC technologies the power losses are calculated directly from the electrical resistance and impedance properties of each technology and associated equipment. Table D.10 provides a summary of circuit resistance data for each AC technology and capacity options considered in this Report.

Table D.10 – AC circuit technologies and associated resistance per circuit

IET, PB/CCI Report short-form label	**AC Overhead Line Conductor Type (complete single circuit resistance for conductor set)**	**AC Underground Cable Type (complete single circuit resistance for conductor set)**	**AC Gas Insulated Line (GIL) Type (complete single circuit resistance for conductor set)**
Lo	2 x 570 mm^2 (0.025 Ω/km)	1 x 2500 mm^2 (0.013 Ω/km*)	Single Tube per phase (0.0086 Ω/km)
Med	2 x 850 mm^2 (0.0184 Ω/km)	2 x 2500 mm^2 (0.0065 Ω/km*)	Single Tube per phase (0.0086 Ω/km)
Hi	3 x 700 mm^2 (0.014 Ω/km)	3 x 2500 mm^2 (0.0043 Ω/km*)	Two tubes per phase (0.0065 Ω/km)
Losses per 200Mvar Reactor required for AC underground cables			
Reactor Losses	N/A	0.4MW per reactor	N/A
Additional losses for 275kV circuits requiring connection to the 400 kV system			
275 kV options only 275/400 kV SGT losses	0.2576 Ω (plus 83 kW of iron losses) per SGT	0.2576 Ω (plus 83 kW of iron losses) per SGT	0.2576 Ω (plus 83 kW of iron losses) per SGT

1.11.6 The process of converting AC power to DC is not 100% efficient. Power losses occur in all elements of the converter station: the valves, transformers, reactive compensation/filtering and auxiliary plant. Manufacturers typically represent these losses in the form of an overall percentage. Table D.11 below shows the typical percentage losses encountered in the conversion process, ignoring losses in the DC cable circuits themselves.

Table D.11 – HVDC circuit technologies and associated resistance per circuit

HVDC Converter Type	2 GW Converter Station losses	2GW DC Cable Pair Losses	2GW Total Link loss
Current Source (CSC) Technology or “Classic” HVDC	0.5% per converter	Ignored	1% per HVDC Link
Voltage Source (VSC) Technology HVDC	1.0% per converter	Ignored	2% per HVDC Link

1.11.7 The example calculation explained in detail below is for “Med” category circuits and has been selected to demonstrate the principles of the mathematics set out in this section. This example does not describe specific options set out within this report. A detailed example explanation of the calculations used to calculate AC losses is included in 0.

1.11.8 The circuit category, for options contained within this report, is set out within each option. The example below demonstrates the mathematics and principles, which is equally applicable to “Lo”, “Med” and “Hi” category circuits, over any distance.

1.11.9 The example calculations (using calculation methodology described in 0) of instantaneous losses for each technology option for an example circuit of 40 km “Med” capacity 6380 MVA (two x 3190 MVA).

- Overhead Lines = (2 x 3) x 1565.5 A2 x (40 x 0.0184 Ω/km) = 10.8 MW
- Underground Cable = (2 x 3) x1565.5 A^2 x (40 x 0.0065 Ω/km) + (6 x 0.4MW) = 6.2 MW
- Gas Insulated Lines = (2 x 3) x 1565.5 A2 x (40 x 0.0086 Ω/km) = 5.1 MW
- CSC HVDC = 34% x 6380 MW x 1% = 21.7 MW
- VSC HVDC = 34% x 6380 MW x 2% = 43.4 MW

1.11.10 An annual loss figure can be calculated from the instantaneous loss. National Grid multiplies the instantaneous loss figure by the number of hours in a year and also by the cost of energy. National Grid uses £60/MWhr.

1.11.11 The following is a summary of National Grid’s example calculations of Annual Losses and Maintenance costs for each technology option for an example circuit of 40 km “Med” capacity 6380 MVA (two x 3190 MVA).

- Overhead Line annual loss = 10.8 MW x 24 x 365 x £60/MWhr = £5.7m.
- U-ground Cable annual loss = 6.2 MW x 24 x 365 x £60/MWhr = £3.3m.
- Gas Insulated lines annual loss = 5.1 MW x 24 x 365 x £60/MWhr = £2.7m
- CSC HVDC annual loss = 21.7 MW x 24 x 365 x £60/MWhr = £11.4m
- VSC HVDC annual loss = 43.4 MW x 24 x 365 x £60/MWhr = £22.8m

1.12 Example Lifetime costs and NPV Cost Estimate

1.12.1 The annual Operation, Maintenance and loss information is assessed against the NPV model at 3.5% over 40 years and added to the capital costs to provide a lifetime cost for each technology.

1.12.2 Table D.12 shows an example for a "Med" capacity route 6380 MVA (2 x 3190 MVA) 400 kV, 40km in length over 40 years.

Table D.12 – Example Lifetime Cost table (rounded to the nearest £m)

Example 400 kV "Med" Capacity over 40km	Overhead Line (OHL)	AC Underground Cable (AC Cable)	Gas Insulated Line (GIL)	CSC High Voltage Direct Current (HVDC)	VSC High Voltage Direct Current (HVDC)
Capital Cost	£145.6m	£1167.6m	£1,244.8m	£1,795.8m	£1,973.9m
NPV Loss Cost over 40 years at 3.5% discount rate	£125m	£62.6m	£58.4m	£235.6m	£471.2m
NPV Maintenance Cost over 40 years at 3.5% discount rate	£2.33m	£5.5m	£2.4m	£171.7m	£171.7m
Lifetime Cost	£273m	£1,236m	£1,306m	£2,203m	£2,617m

Appendix E: Mathematical Principles used for AC Loss Calculation

1.1.1 This Appendix provides a detailed description of the mathematical formulae and principles that National Grid applies when calculating transmission system losses. The calculations use recognised mathematical equations which can be found in power system analysis text books.

1.1.2 The example calculation explained in detail below is for “Med” category circuits and has been selected to demonstrate the principles of the mathematics set out in this section. This example does not describe specific options set out within this report.

1.1.3 The circuit category, for options contained within this report, is set out within each option. The example below demonstrates the mathematics and principles, which is equally applicable to “Lo”, “Med” and “Hi” category circuits, over any distance.

1.2 Example Loss Calculation (1) – 40 km 400 kV “Med” Category Circuits

1.2.1 The following is an example loss calculation for a 40 km 400 kV “Med” category (capacity of 6,380 MVA made up of two 3,190 MVA circuits).

1.2.2 Firstly, the current flowing in each of the two circuits is calculated from the three phase power equation of $P = \sqrt{3} V_{LL} I_{LL} \cos\theta$. Assuming a unity power factor ($\cos\theta = 1$), the current in each circuit can be calculated using a rearranged form of the three phase power equation of:

(In a star (Y) configuration electrical system $I = I_{LL} = I_{LN}$)

$I = P/\sqrt{3} V_{LL}$

Where, P is the circuit utilisation power, which is 34% of circuit rating as set out in D.40 of 0, which for the each of the two circuits in the “Med” category example is calculated as:

P = 34% x 3190 MVA = 1,084.6 MVA

and, V_{LL} is the line to line voltage which for this example is 400 kV.

For this example, the average current flowing in each of the two circuits is:

I = 1,084.6 x 106/(√3 x 400 x 103) = 1,565.5 Amps

1.2.3 The current calculated above will flow in each of the phases of the three phase circuit. Therefore from this value it is possible to calculate the instantaneous loss which occurs at the 34% utilisation loading factor against circuit rating for any AC technology.

1.2.4 For this “Med” category example, the total resistance for each technology option is calculated (from information in 0, Table D.10) as follows:

Overhead Line = 0.0184Ω/km x 40 km = 0.736 Ω

Cable Circuit[27] = 0.0065Ω/km x 40 km = 0.26 Ω

Gas Insulated Line = 0.0086Ω/km x 40 km = 0.344 Ω

These circuit resistance values are the total resistance seen in each phase of that particular technology taking account the number of conductors needed for each technology option.

1.2.5 The following is a total instantaneous loss calculation for the underground cable technology option for the "Med" category example:

Losses per phase are calculated using $P=I^2R$

1,565.52 x 0.26 = 0.64 MW

Losses per circuit are calculated using $P=3I^2R$

3 x 1,565.52 x 0.26 = 1.91 MW

Losses for "Med" category are calculated by multiplying losses per circuit by number of circuits in the category.

2 x 1.91 MW = 3.8 MW

1.2.6 For underground cable circuits, three reactors per circuit are required (six in total for the two circuits in the "Med" category). Each of these reactors has a loss of 0.4 MW. The total instantaneous losses for this "Med" category example with the underground cable technology option are assessed as:

3.8 + (6 x 0.4) = 6.2 MW

1.2.7 The same methodology is applied for the other AC technology option types for the "Med" category example considered in this Appendix. The following is a summary of the instantaneous total losses that were assessed for each technology option:

Overhead Lines = (2 x 3) x 1,565.52 x 0.736 = 10.8 MW

Cables = (2 x 3) x 1,565.52 x 0.26 + (6 x 0.4) = 6.2 MW

Gas Insulated Lines = (2 x 3) x 1,565.52 x 0.344 = 5.1 MW

1.3 Example Loss Calculation (2) – 40 km 275 kV "Lo" Category Circuits Connecting to a 400 kV part of the National Grid's transmission system

1.3.1 The following is an example loss calculation for a 40 km 275 kV "Lo" category (capacity of 3,190 MVA made up of two 1,595 MVA circuits) and includes details of how losses of the supergrid transformer ("SGT") connections to 400 kV circuits are assessed. This example assesses the losses associated with the GIL technology option up to a connection point to the 400 kV system.

[27] A 40 km three phase underground cable circuit will also require three reactors to ensure that reactive gain is managed within required limits.

1.3.2 The circuit utilisation power (P) which for the each of the two circuits in the “Lo” category example is calculated as:

$P = 34\% \times 1{,}595 = 542.3$ MVA

For this example, the average current flowing in each of the two circuits is:

$I = 542.3 \times 10^6 / (\sqrt{3} \times 275 \times 10^3) = 1{,}138.5$ Amps

1.3.3 For this “Lo” category example, the total resistance for the GIL technology option is calculated (from information in 0, Table D.10) as follows:

$0.0086\Omega/\text{km} \times 40 \text{ km} = 0.344\ \Omega$

1.3.4 The following is a total instantaneous loss calculation for the GIL technology option for this “Lo” category example:

Losses per circuit are calculated using $P=3I^2R$

$3 \times 1138.5 \times 0.344 = 1.35$ MW

Losses for “Lo” category 275 kV circuits are calculated by multiplying losses per circuit by number of circuits in the category

$2 \times 1.35 \text{ MW} = 2.7$ MW

1.3.5 SGT losses also need to be included as part of the assessment for this “Lo” category example which includes connection to 400 kV circuits. SGT resistance[28] is calculated (from information in 0, Table D.10) as 0.2576 Ω.

1.3.6 The following is a total instantaneous loss calculation for the SGT connection part of this “Lo” category example:

The average current flowing in each of the two SGT 400 kV winding are calculated as:

$I_{HV} = 542.3 \times 10^6 / (\sqrt{3} \times 400 \times 10^3) = 782.7$ Amps

Losses per SGT are calculated using $P=3I^2R$

SGT Loss = $3 \times 782.7 \times 0.2576 = 0.475$ MW

Iron Losses in each SGT = 84kW

Total SGT instantaneous loss (one SGT per GIL circuit) = $(2 \times 0.475) + (2 \times 0.084) = 1.1$ MW.

1.3.7 For this example, the total “Lo” category loss is the sum of the calculated GIL and SGT total loss figures:

“Lo” category loss = 2.7 + 1.1 = 3.8 MW

[28] Resistance value referred to the 400 kV side of the transformer.

Appendix F: Land-based alternative of preferred option EGL OPP6 (land)

1.1 Overview of EGL OPP6 (land)

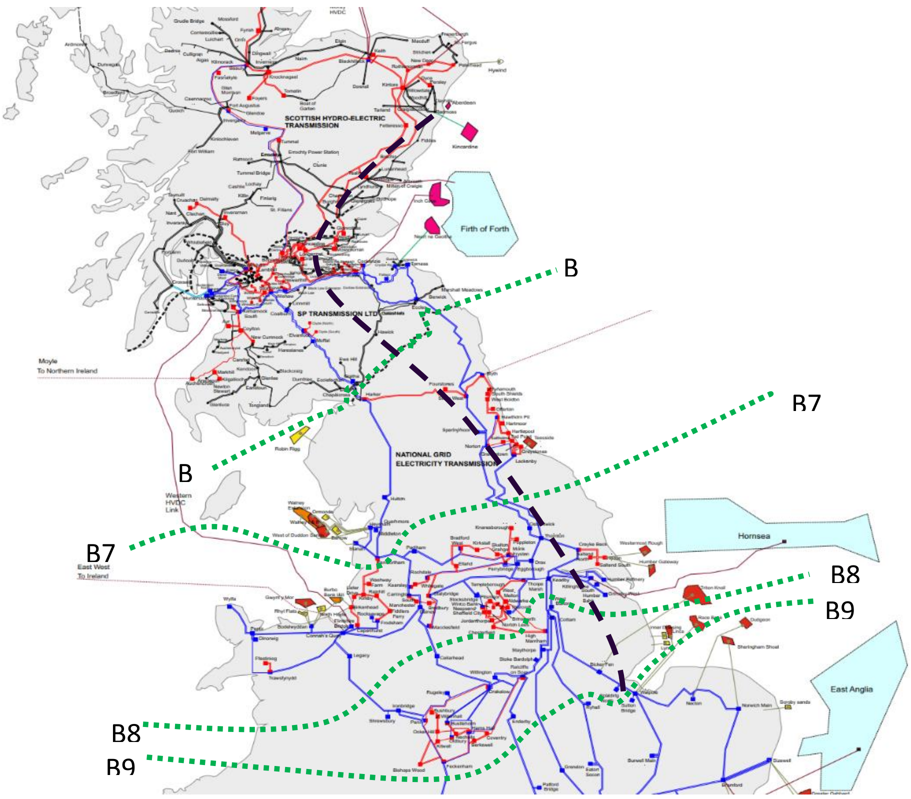
1.1.1 As set out in Section 5, NGET investigated the technology choice (subsea HVDC) set out in the ESO recommendations in respect of additional transmission system connections on the East Coast of Scotland and England.

1.1.2 An onshore reinforcement option was identified that is broadly equivalent to the proposed connection of two, new HVDC links which is based on the preferred strategic option for the connection of two new HVDC links that is identified in this report. This option EGL OPP6 (land) illustration is provided to show the key factors NGET considered as part of this investigation and the reasons why this option was not progressed as a potential strategic option.

1.1.3 Option EGL OPP6 (land) would require construction of a new High Capacity 6930MW double circuit that crosses through Scotland and North East England to East Anglia (from Peterhead in Scotland, via West Fife to the new Walpole substation).

1.1.4 In accordance with the methodology set out in Section 6, the circuit distance considered for this new Peterhead – West Fife – Walpole connection was 640km x 20% routing = 768km.

Figure H.1 – EGL OPP6 (land) New Walpole Substation



1.1.5 For the appraisal of onshore options of significant distance, an overhead line would normally be expected to offer the most economic, efficient, and coordinated development and therefore would meet NGET's obligations under section 9 of the Electricity Act. Therefore, prior to consultation on any required mitigation the environmental and socio-economic appraisal, which takes into consideration NGET's duty to have regard to the environment in Schedule 9, has sought to establish the impacts of the proposal based upon an assumed use of overhead line technology. This enables the appraisal to highlight areas of highest impact aiding discussions throughout the consultation stage of the project.

1.1.6 A new overhead line route from the north east and east of Scotland to the Walpole substation would encounter and potentially impact on a number environmental and socio-economic constraints including a range of statutory designated landscapes, National Parks and statutory ecological and historic environment designations as well as being routed close to or through urbanised areas impacting on settlements. While many environmental and socio-economic impacts could be mitigated through careful route selection and appropriate mitigation including undergrounding sections of the route, this option would result in greater environmental and socio-economic impacts compared to alternative subsea HVDC links. The potential impacts of this option would affect its deliverability, in particular whether such an overhead line could be consented and constructed by 2030.

1.1.7 Overall, this option would be expected to result in a greater level of environmental and socio-economic impact compared to the subsea HVDC options considered (OPP1 to 7) and does not provide any benefit over those options and therefore is less preferable.

1.1.8 The EGL OPP6 (land) alternative option would meet the need case set out in this report, provided that the following transmission works were carried out:

- New Circuit requirements
    a) Land based AC connections for 400kV double circuit options using Med capacity double circuits (two 400 kV AC circuits) with a total capacity of up to 6380 mega volt amperes (MVA) of a distance of 768km; or
    b) HVDC connection options using 525 kV 2 GW voltage source links, which would require a converter station at each end, similar in size to a large warehouse. In this case a 4 GW connection would require four converter stations in total, with up to two of the converters located at the new Walpole substation
    c) 400kV circuits of 768km in length.
- NGET Substation Works
    a) 2- 4 new bays at the new Walpole substation(s) and connections to the converter stations.

1.1.9 Technical analysis of this option included the following:

- This option for a land based circuit would cover a significant length of the country and due to the length being greater than >500km, AC option are likely to see a lower load limit than circuit rating due to the high impedance of AC circuits over 500km in length.
- It is likely that an AC overhead line option of such length would require some sections of mitigation to limit impact on designations or due to natural features and this would increase the cost of this option.
- The option will significantly increase the loading on the existing circuits flowing south from the new Walpole substation, however multiple transmission circuits will connect the site so this impact is limited. This is compared to the HVDC solution where power flows over this long distance are controlled.

1.1.10 We undertook a cost evaluation of the following four technologies for onshore options evaluation:

- 400 kV AC overhead Line
- 400 kV AC underground cable
- 400 kV AC gas insulated line (GIL)
- 525 kV HVDC underground cable

1.1.11 Table below sets out the capital costs for option EGL OPP6 (land)

Table H.1 – Option EGL OPP6 (land): capital cost for each technology option

Item	**Need**	**EGL OPP6 (land) Capital Cost**			
Substation Works	Facilitate Generation and connect new circuits	£120.0m			
New Circuits		**AC OHL**	**AC Cable**	**AC GIL**	**HVDC (4GW)**
New Circuit 768 km	New Circuit across E5C North	£3,056.6m	£33,309.1m	£33,223.7m	£5,815.0m
Total Capital Cost		**£3,176.6m**	**£33,429.1m**	**£33,343.7m**	**£5,935.0m**

1.1.12 Table below sets out the lifetime cost for the new circuit options, the lifetime costs are different for each circuit technology and are included as a differentiator between technologies. These costs are calculated using the methodology described in "Strategic options technical appendix 2020/2021 price base" Appendix D.

Table H.2 – Option EGL OPP6 (land): lifetime cost for each technology option

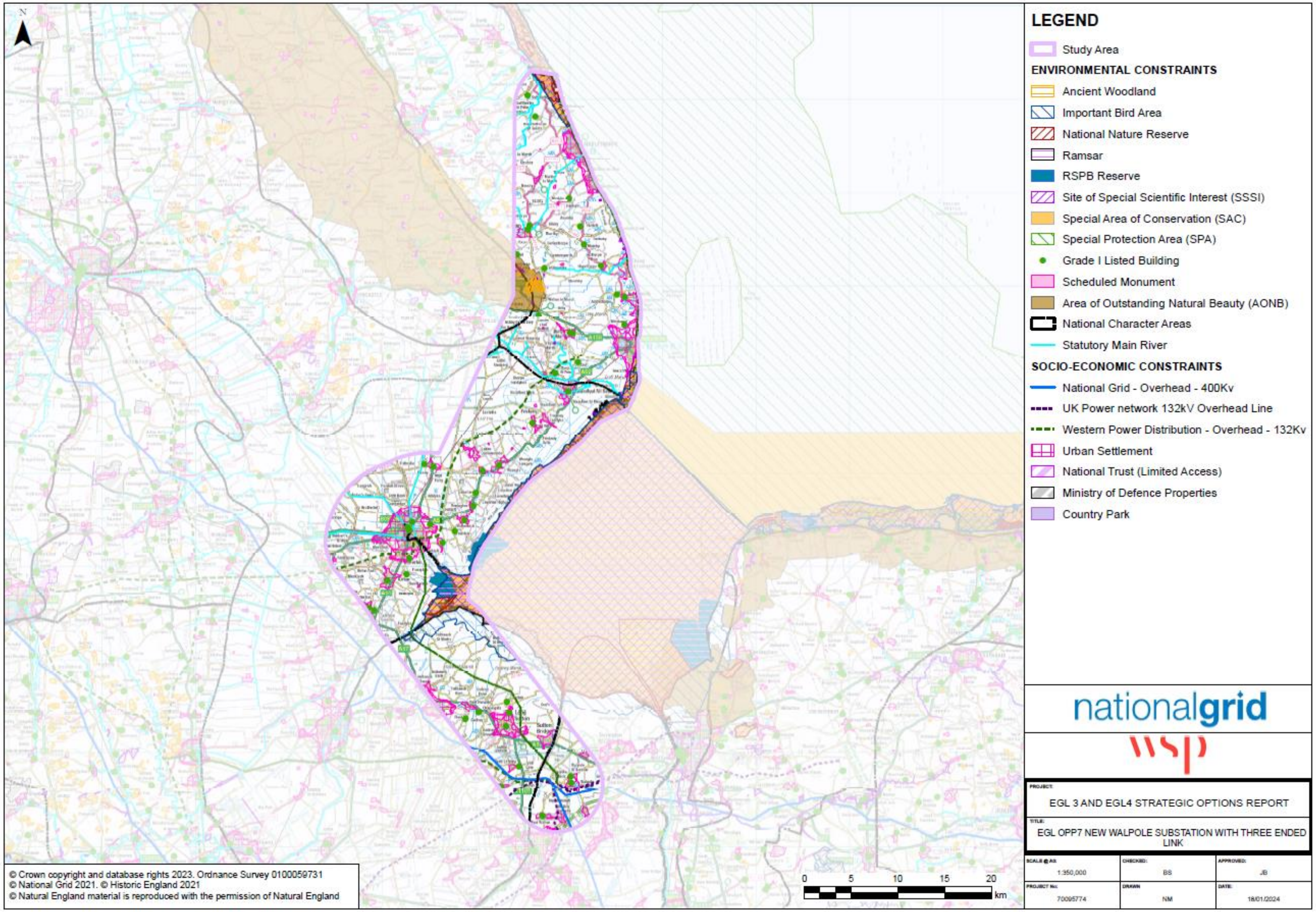
Land Based Option	EGL OPP6 (land) Lifetime Cost			
	AC OHL	AC Cable	AC GIL	HVDC
Capital Cost of New Circuits	£3,056.6m	£33,309.1m	£33,223.7m	£5,815.0m
NPV of Cost of Losses over 40 years	£2,154.4m	£1,715.0m	£1,000.3m	£314.1m
NPV of Operation & Maintenance Costs over 40 Years	£44.9m	£161.4m	£45.2m	£178.0m
Lifetime Cost of New Circuits	**£5,256m**	**£35,186m**	**£34,269m**	**£6,248m**

1.1.13 Based on the findings from this indicative evaluation of EGL OPP6 (land) a 6830MW AC connection between Scotland and England with a connection location for the new circuits at the new Walpole substation, was identified as the preferred land based option. In light of this analysis our starting presumption for further development of this option should it be selected, would be for a majority overhead line connection.

1.1.14 Comparing the estimated capital cost of £3,176.6m for the EGL OPP6 (land) option to our preferred HVDC option estimated capital cost of £4,822.6m, the difference is significant. However, the lifetime cost for the overhead line is £5,256m compared to £5,540m for the HVDC, therefore in this case, the HVDC option offers very comparable value to consumers over its lifetime. It should be noted over the distance proposed the needs for mitigation of an overhead line option is likely to be required increasing the cost of the land based option.

1.1.15 If just 5% (40km) of the overhead line (with circuit length of over 700km) required some underground mitigation through some sensitive areas, this would increase the capital cost by over £1,500m. Over such long distances (>500km), HVDC becomes competitive especially in comparison of lifetime costs. In this case, NGET decided not to progress option EGA OPP6 (land) for further development.

Appendix G: Study areas used to appraise the environmental and socio-economic impacts of options



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